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Comparison of Nimbus-7 TOMS Version 6 and 7 Ozone Fields by Space-time Spectral Analysis

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Abstract

Total column ozone fields from Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) version 7 (V7) data are analyzed by space-time spectral analysis and compared with previous analyses of version 6 (V6) data. One purpose of this note is to briefly comment on some differences between these two data sets. A second purpose is to help prospective TOMS users avoid several pitfalls inherent in analyzing TOMS data. Among the differences noted are improvements in the treatments of the known wave 1 low latitude feature and of large solar zenith angle effects at high latitudes. A variety of low amplitude, traveling features are noted, some of which are atmospheric in origin and some of which may be related to the satellite orbital characteristics or retrieval methods. Interpretations of these in terms of atmospheric dynamics should thus be made with care. Overall, the sensitive tests provided by space-time decomposition suggest that TOMS version 7 constitute an improved global data set valuable for investigations of total ozone.

1. Introduction

Fast Fourier transform (FFT) space-time spectral analyses have been previously applied to the extensive (November 1978-May 1993) global total ozone fields from Nimbus-7 TOMS version 6 [*Stanford et al.*, 1995]. The present note compares similar analyses of the newly completed TOMS version 7 retrievals. Such analyses can provide sensitive tests of the internal consistency of such data sets, as well as diagnose various standing and traveling wave features in the data.

2. Data and analyses of version 7 TOMS data

Except for section 3 and Figures 24–25, the version 7 data analyzed were in the form of daily grids of 5° latitude (85° S to 85° N) by 15° longitude blocks, the same used with the previous version 6 analyses by *Stanford et al.* [1995]. This significantly reduced memory requirements compared with the original 1° latitude by 1.25° longitude data set. In addition, use of the lower-resolution data effectively eliminates a known artifact related to the approximate 14 orbits per day of Nimbus-7. The latter effect appears in the higher resolution global gridded data as an approximate zonal wave 14 (14 wavelengths fit around a latitude circle), westward moving low latitude wave with period near 5.7 days. This data artifact is discussed in the following section.

The space-time analyses were performed with FFT techniques as described in *Stanford et al.* [1995]. Time versus longitude plots at various latitudes are used for these comparisons. Both total column and spectrally-decomposed ozone data for three nonconsecutive years are considered. For each year, plots were made for 13 latitudes from 60° S to 60° N, in 10° increments.

The 5° by 15° data sets were produced from the 1° by 1.25° data set by Gaussian 3-D interpolation over latitude, longitude, and time. A linear interpolation in time supplied the remaining missing data. After binning to a 5° by 5° grid, zonal waves 0 (zonal mean) through 12 were obtained by an FFT routine. In addition to avoiding the wave 14 artifact mentioned in section 3, this also reduces noise. Every third zonal point was then sampled to achieve the 5° by 15° fields.

Many of the differences noted here are known to members of the Goddard Ozone Processing Team but are included here for the sake of completeness, since the document is intended for the use of potential TOMS users elsewhere.

3. Gridding artifact seen in spectral analysis

As one illustration of the usefulness and sensitivity of space-time analysis of TOMS, we briefly describe a data processing artifact found in the analyses. The 5° by 5° TOMS data set was used for this analysis. Figures 1*a* and 1*b* show eastward/westward spectral amplitudes for zonal wave 14 covering years 1979–1992. Seen in these figures is a peculiar spectral feature with period near 6 days. While there is a known westward propagating zonal wavenumber 1 atmospheric global normal mode with period around 5 days, the feature seen here is not related to it. Reasons for this assertion are first, that the spectral peak in Figures 1*a* and 1*b* is exceptionally sharp, having a period that is always very close to 5.7 days, throughout the entire 14-year TOMS; this is too sharp for a wave mode in the real atmosphere. Second, the main contribution was found to occur at wave 14, suspiciously close to the number of orbits per day, with respect to the Earth grid, made by the sun-synchronous Nimbus-7 satellite. This feature is an artifact related to the original process of producing the CD-ROM total ozone grids. The effect is strongest in low latitudes where orbital scans do not overlap. Moreover, largest amplitudes in Figures 1*a* and 1*b* are directly related to aerosol loading of the stratosphere, being strongest after two major volcanic eruptions that occurred during the TOMS record, the Mexican El Chichon in early 1982 and Mt. Pinatubo in the Philippines in mid-1991. These artifacts are strongest at 20° N after El Chichon and at 10° S after Pinatubo (Figures 1*a* and 1*b*, respectively). In years of more normal aerosol loading in the stratosphere, errors are seen to be much reduced in magnitude. Note that this artifact is nearly identical in version 6 TOMS data as well [*Stanford et al.*, 1995]. To summarize, scan angle/gridding effects in version 7 TOMS produce an artificial westward traveling wave 14 with period near 5.7 days and magnitude ~1–5 Dobson units (DU) in low latitudes. Space-time spectral analysis thus provides a sensitive tool for detection of data processing artifacts.

Because of the artifact mentioned above, unless higher resolution is specifically required, we recommend using the 5° by 15° TOMS data set.

4. Comparison of version 6 and 7 TOMS fields

On all plots included here, positive (negative) values are displayed as solid (dotted) contours. Since the negative contours are frequently hard to discern or do not exist (on the total column ozone plots), a different dash-dot pattern is used to represent the first positive contour greater than zero in these cases. Also, some plots do not show the zero level contour and are noted as such. Where shown, the zero level is a solid contour.

a. General comparisons

Although there are isolated places in time and space where the opposite is true, V6 ozone values are greater than V7 at nearly all times and latitudes. This is at least partially due to the wavelength calibration error that was corrected in V7 [*Seftor et al.*, 1996]. The best example of where V7 tends to be greater than V6 over large areas is at high latitudes near the beginning of winter. Figures 2, 3 and 4 show the total ozone comparisons for 60° N, equator and 60° S during 1989. Figure 5 shows the results for 60° N in 1981. The two left-most columns are V6 and V7, respectively, while the difference V6–V7 is given in DU and in percentage of V6 in the remaining two columns. Because time increases downwards in these Hovmoller-type plots, eastward moving ozone features appear as blobs moving from left to right and downwards.

Figures 2 and 5 show that the only appreciable regions where V7 exceeds V6 (dotted contours on plots) at 60° N occur at the beginning of winter and tend to be between 90° W and 90° E. At the equator (Figure 3) V6 generally dominates (solid and dash-dot contours on plot). All years analyzed exhibited similar results.

The magnitude of the differences between the two data sets seem to be greater in the winter of both hemispheres, and the greatest differences were found to occur at high latitudes in all years examined. This is probably related to known problems in the V6 retrievals at high solar zenith angles. In general, the maximum differences were found to be ∼15–18%. The greatest difference occurred at 60° N in 1981 (Figure 5).

Large differences occur year-round near the dateline (180°) at high latitudes (compare percent difference plots in Figures 2–5). In the equatorial and lower latitude regions, the greater differences are primarily observed near the Greenwich meridian (center of the plots). The latter is discussed further in section 4c. At midlatitudes (not shown here) the clustering of V6–V7 differences near the dateline or Greenwich meridian is less apparent. This phenomenon is present in all years analyzed.

At 60° S in early winter (Figure 4, May–June), eastward moving features are enhanced in V7, and are probably related to eastward moving atmospheric features known to occur with these time and space scales. Thus, V7 evidently does better than V6 in capturing planetary waves in ozone at high solar zenith angles.

b. Space-time analysis comparisons

Space-time FFT decomposition of the daily total ozone fields reveals several interesting differences between TOMS V6 and V7. Figures 6 and 7 show spectral decomposition of the ozone fields into zonal waves 1-7 at 40° S in 1985 for V6 and V7, respectively. Wave 1 refers to one wavelength fitting around a latitude circle, wave 2 refers to two wavelengths, and so on. Contours slanting downwards from left to right (for example, wave 2 during September) indicate eastward moving wave components. The difference (V6–V7) between the two sets at midlatitudes (40°S) is shown in Figure 8. With the exception of occasional cases of rapid phase shifts at low amplitudes, space-time wave analyses reveal little difference between V6 and V7 data sets at middle latitudes. Compare the wave 1 plots in Figures 6 and 7 near the end of January and the middle of March for two examples of these rapid phase shift differences in the two data sets.

The differences in phase movement seen here are evidently due to retrieval differences between V6 and V7. That such differences exist is hardly surprising: in the analysis of low amplitude signals, relatively small changes in amplitude can result in rapid phase shifts. From a standpoint of dynamical wave studies, the central question is which version is more representative of the atmosphere. Based on the overall analyses presented here, our opinion is that V7 is better. However, identifying artifacts in the data can be difficult and in cases of question, TOMS data users are well advised to consult with the Goddard Ozone Processing Team.

At low latitudes, differences are more apparent. Figures 9–11 present space-time analyses at 20° N latitude for 1981. Of potential relevance for small amplitude wave studies are the differences in some traveling features in the two data sets. The most significant differences occur in wave 2, from mid-April through mid-November. For example, from September to November, wave 2 is fairly stationary in V6 while exhibiting westward motion in V7. For several months previous to this the opposite is true, with V6 wave features moving westward while V7 shows more stationary wave 2. These low latitude differences in the motions of features occur throughout the years analyzed (although less frequently than the rapid phase shifts noted above).

The difference of the spectrally analyzed fields (Figure 11) reveals pronounced patterns, mostly stationary in time, and maximum differences of ~ 5 DU at 20° N. These low latitude differences are attributed to desert dust corrections in version 7 TOMS. We note that version 7 TOMS will still not be able to detect ozone that lies below dust; however, this effect is generally small, contributing only a few DU in error (P. K. Bhartia, personal communication, 1997).

A number of low amplitude features in TOMS data have been previously identified with atmospheric dynamical modes such as Rossby-gravity waves and Kelvin waves [*Stanford and Ziemke*, 1993; *Ziemke and Stanford*, 1994a, 1994b]. Figures 12–14 show space-time analyses for the equator in 1985. The westward moving medium scale (waves 4–7) features occurring during August–September of this year are the Rossby-gravity waves described by *Stanford and Ziemke* [1993]. These westward moving medium scale waves are robust features in the TOMS data, occurring in both V6 and V7. It is worth reiterating, however, that in general it can be difficult to accurately identify relatively low amplitude features in TOMS data and caution is advised.

c. An improved cloud height climatology

Figures 15–18 give comparisons of V6–V7 differences at high, medium and low latitudes. The differences are most noticeable in waves 1 and 2 and at low latitudes. Figure 17 reveals that the difference between V6 and V7 has strong standing 1 and 2 components. These are the V6–V7 differences of the FFT component fields. The phase of wave 1 depends on latitude in all years investigated here. Generally, V6 is greater than V7 at the equator near the Greenwich meridian. At high latitudes, V7 is greater at this longitude. Figures 15, 17 and 18 show this phenomena in 1989 at 60° N, the equator, and 60° S, respectively. In the middle latitudes (Figure 16), the phase does not show a well-defined pattern in time and space.

The persistent differences between V6 and V7 are attributed to the effects of cloud pressure errors in V6 which are significantly reduced by the improved cloud climatology utilized in V7 [*Seftor et al.*, 1996; *Hudson et al.*, 1995; *Thompson et al.*, 1993; *Hsu et al.*, 1997]. Generally, V6 ozone is greater than V7 at low latitudes near the Greenwich meridian (see Figure 2, for example). The low latitude V6 ozone fields are known to systematically overestimate ozone in the tropical south Atlantic, the effect being due to persistent low level cloudiness in that region not captured by the zonal mean cloud statistics used in the V6 retrievals. The monthly mean cloud climatology used in V7 retrievals allows zonal asymmetries, with 2.5° longitude bins, and significantly improves the ability to capture persistent or slowly moving features such as those in the low latitude south Atlantic. Figure 17 shows these persistent wave 1 and 2 differences between V6 and V7. The improved V7 data set has already played an important and major role in several investigations dealing with the dynamics and chemistry of ozone in the tropical south Atlantic (see, for example, *Thompson et al.*, 1993; *Hudson et al.*, 1995; *Ziemke et al.*, 1996].

At low latitudes V6–V7 differences are of smaller magnitude (Figure 17) than at high latitudes where the differences are most noticeable in the corresponding hemispheric winter season (Figures 15 and 18). As noted previously, this is attributed to improvements in the treatment of high solar zenith effects in V7.

Finally, as can be seen in wave 1 of Figure 17, the V6 and V7 wave 1 components are approximately equal during March and April, but not at other times of year. This pattern appears every year at the equator and is most likely attributable to the differences in cloud climatology used in the two versions, V7 likely being the most trustworthy.

d. Volcanic effects

Major volcanic activity is enhanced in V7 TOMS, most likely due to the sulfur dioxide index included with the V7 retrievals. Sulfur dioxide (SO_2) absorbs strongly in the ultraviolet and can seriously contaminate TOMS radiances. This contamination of TOMS ozone is illustrated in Figure 19 that shows V7 exceeding V6 (dotted contours) by as much as $\sim 15\%$ of the total column ozone amounts in June 1991 between the Greenwich meridian and 90° E. This appears to coincide with the location of the plume from the eruption of Mt. Pinatubo at that time. (Ultraviolet absorption by SO_2 and the contaminating effects on TOMS measurements are discussed by *Krueger et al.* [1995].)

Using spectral analysis, the contamination is seen to affect all wavenumbers. Figures 20-22 show that V7 is observably worse than V6 in the presence of volcanic aerosols. Figure 23 shows the space-time root mean square (RMS) amplitudes for the combined zonal wavenumbers 1 to 12 at the equator from January 1979 to December 1992 for V7 data. The black areas in Figures 24 and 25 represent the flagged bad data in the data set. Circumscribing the areas corresponding to the plume of Mt. Pinatubo are anomalously large ozone values. It can be clearly seen how the eruption contaminates the zonal wave amplitudes.

5. Summary

The TOMS total ozone data set is of critical importance for global atmospheric ozone studies. We have briefly compared TOMS version 6 with the new version 7, using the sensitive diagnostic tool of space-time spectral analysis. A number of differences are noted. Overall, the results suggest that version 7 TOMS is generally an improved data set which should have wide use in total ozone investigations.

A number of low amplitude, traveling features are displayed in some detail. While some are known to be related to atmospheric dynamics, others may be artifacts due to orbital geometry or data processing procedures and caution is urged in their interpretation.

Acknowledgments.
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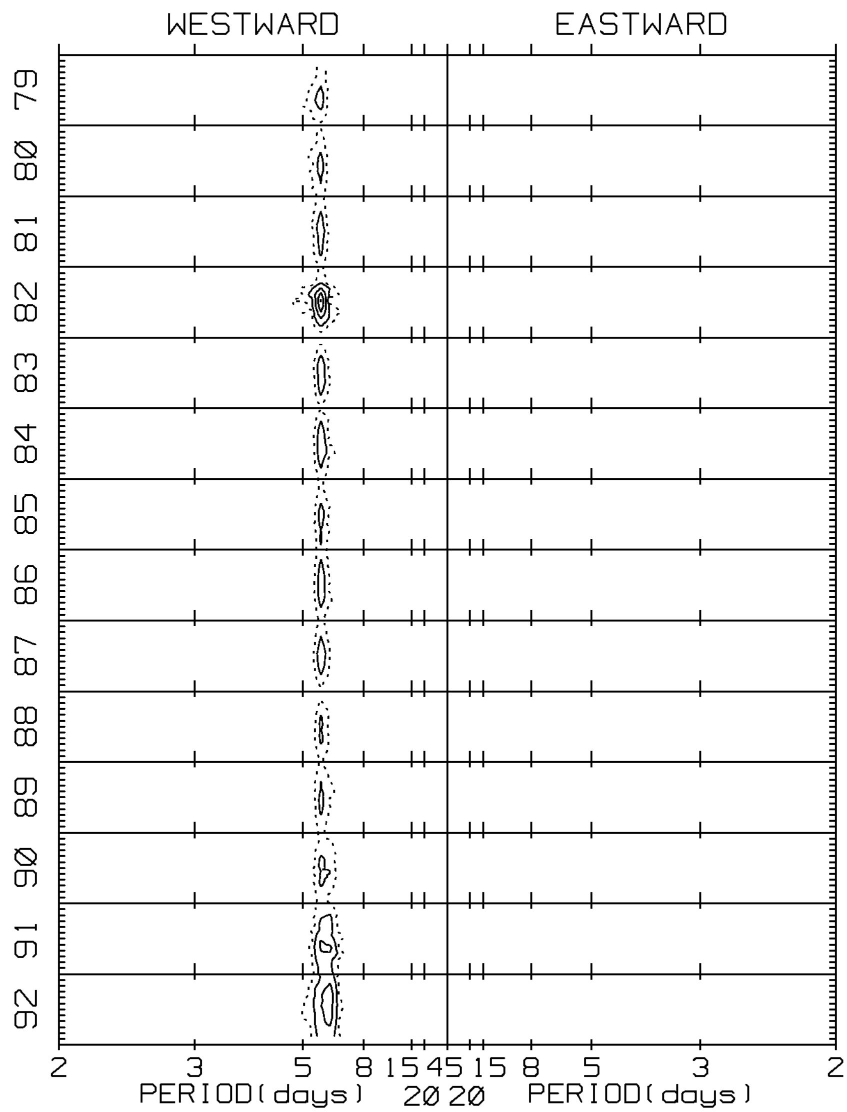

Figure 1a. Time versus frequency (periods in days shown) TOMS eastward/westward spectral amplitudes for zonal wave 14 computed using a 90-day window with a one-month step. Days: 1 January 1979 - 31 December 1992. Units: DU. Dashed (solid) contours 0.5 (1,2,3,...). Latitude: 20° N.

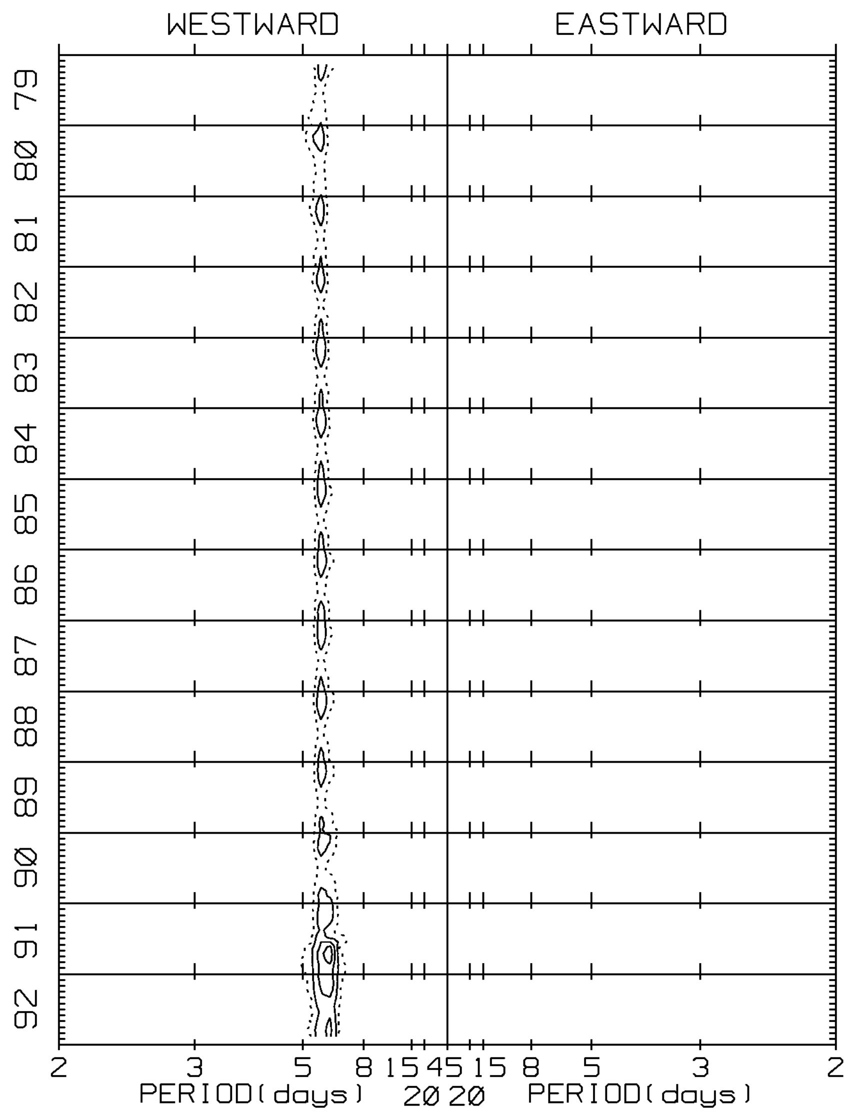

Figure 1b. As in Figure 1a, but at 10° S.

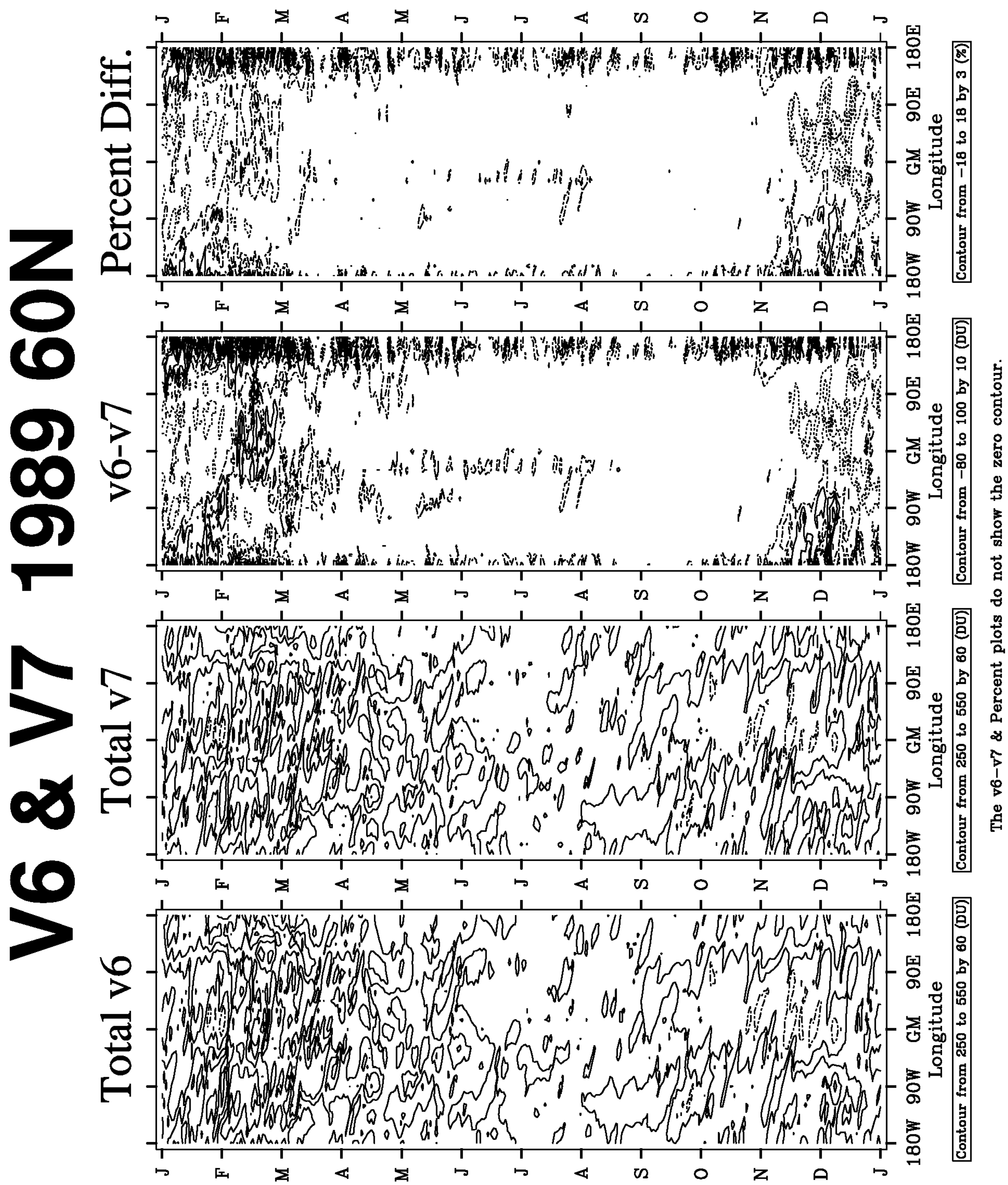

Figure 2. Time versus longitude contour plots of version 6 and version 7 total column ozone, the difference version 6-7, and the percentage difference at 60° N latitude for 1989. Contours: solid contours are positive, dotted are negative, and dash-dotted are lowest positive magnitudes greater than zero. When shown, the zero contour is solid.

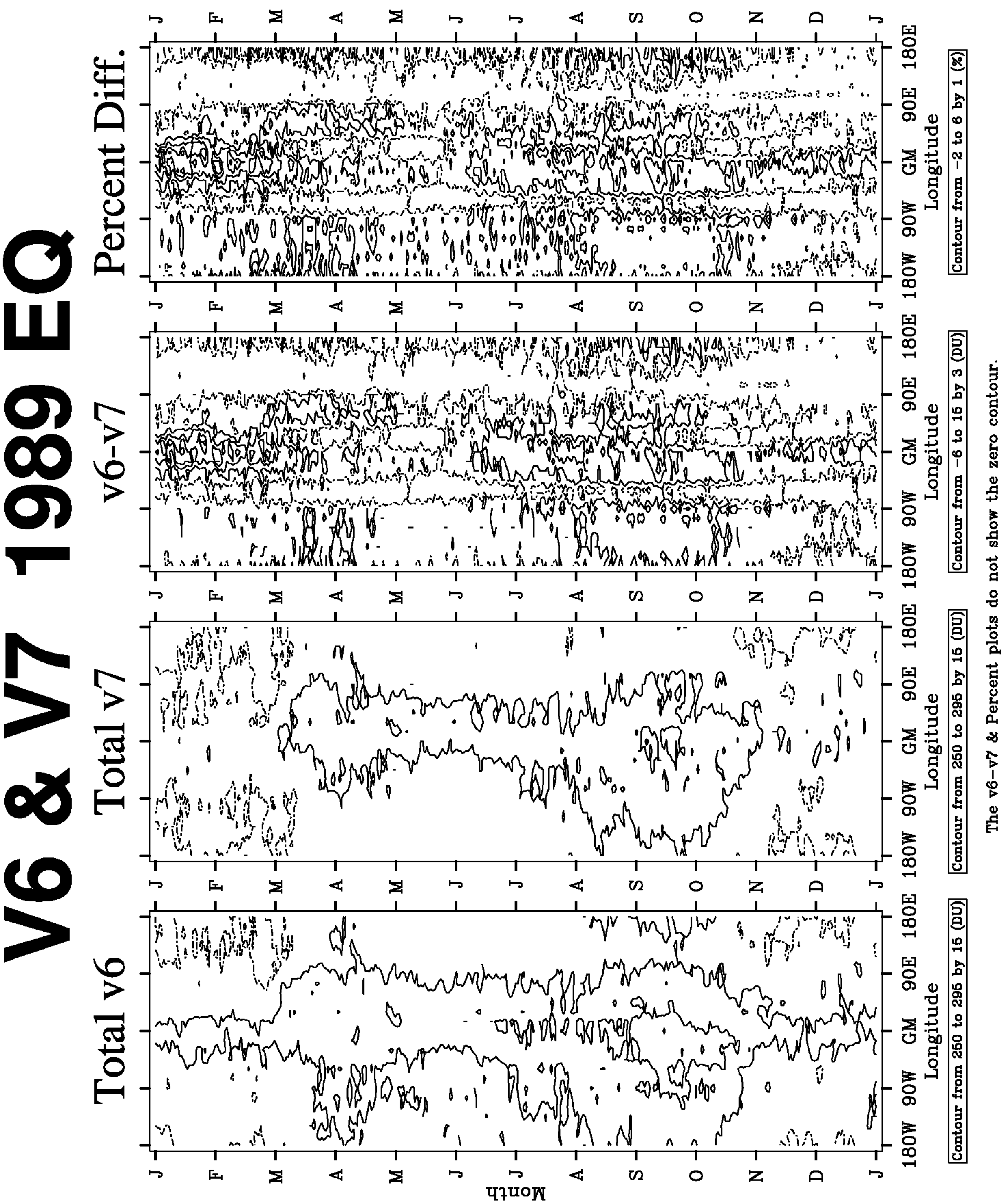

Figure 3. As in Figure 2, but at the equator.

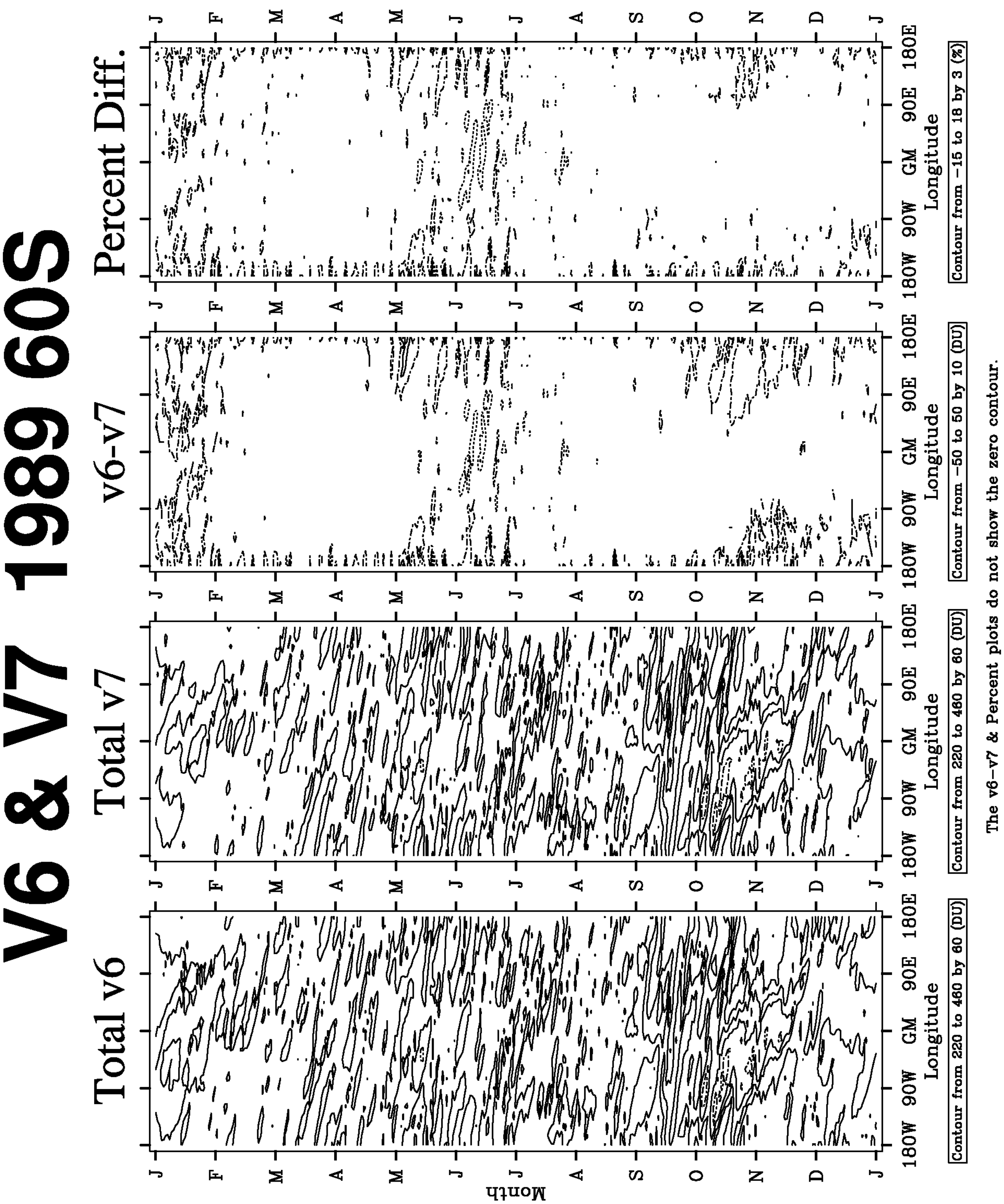

Figure 4. As in Figure 2, but at 60° S latitude.

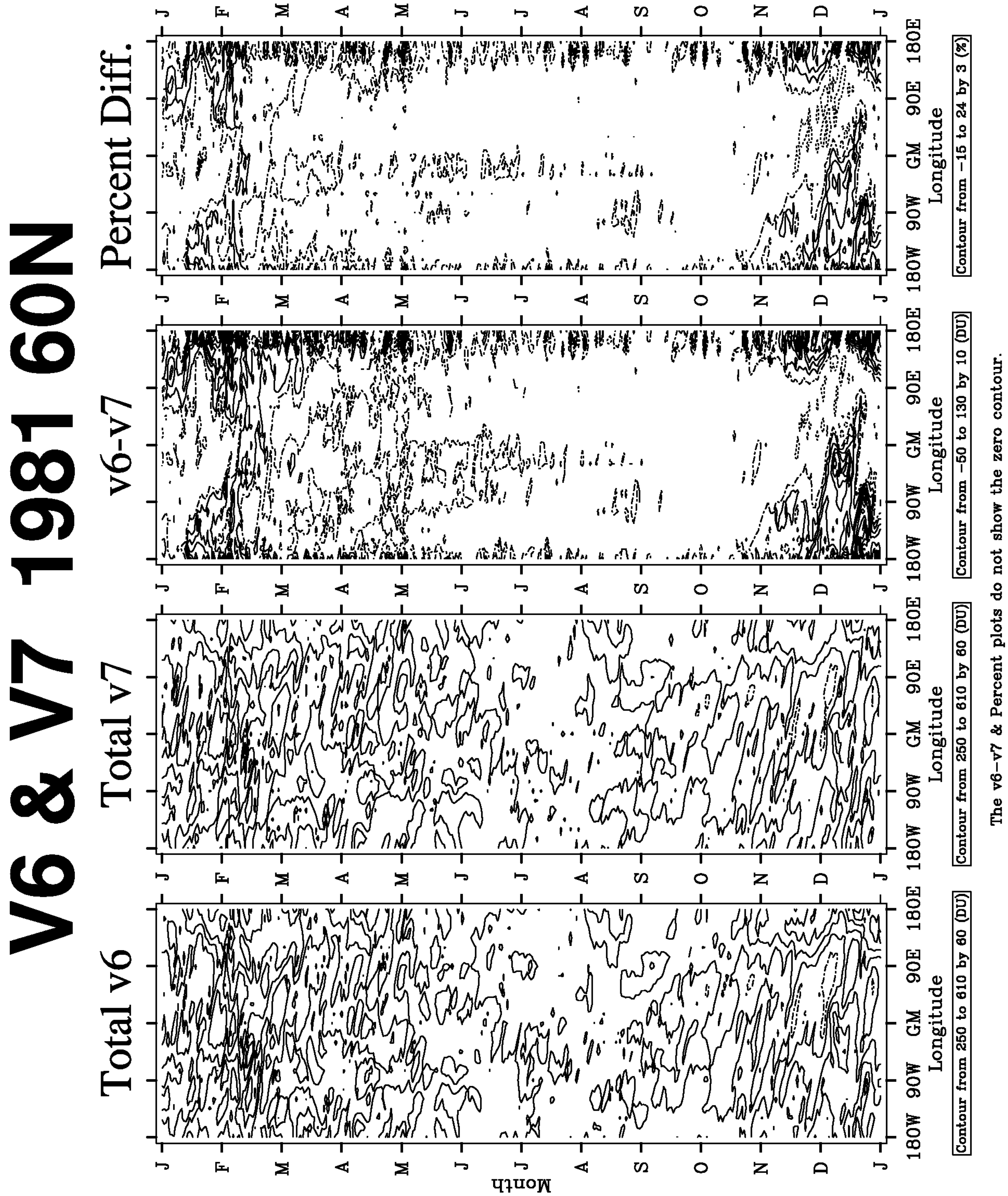

Figure 5. As in Figure 2, but at 60° N latitude and the year 1981.

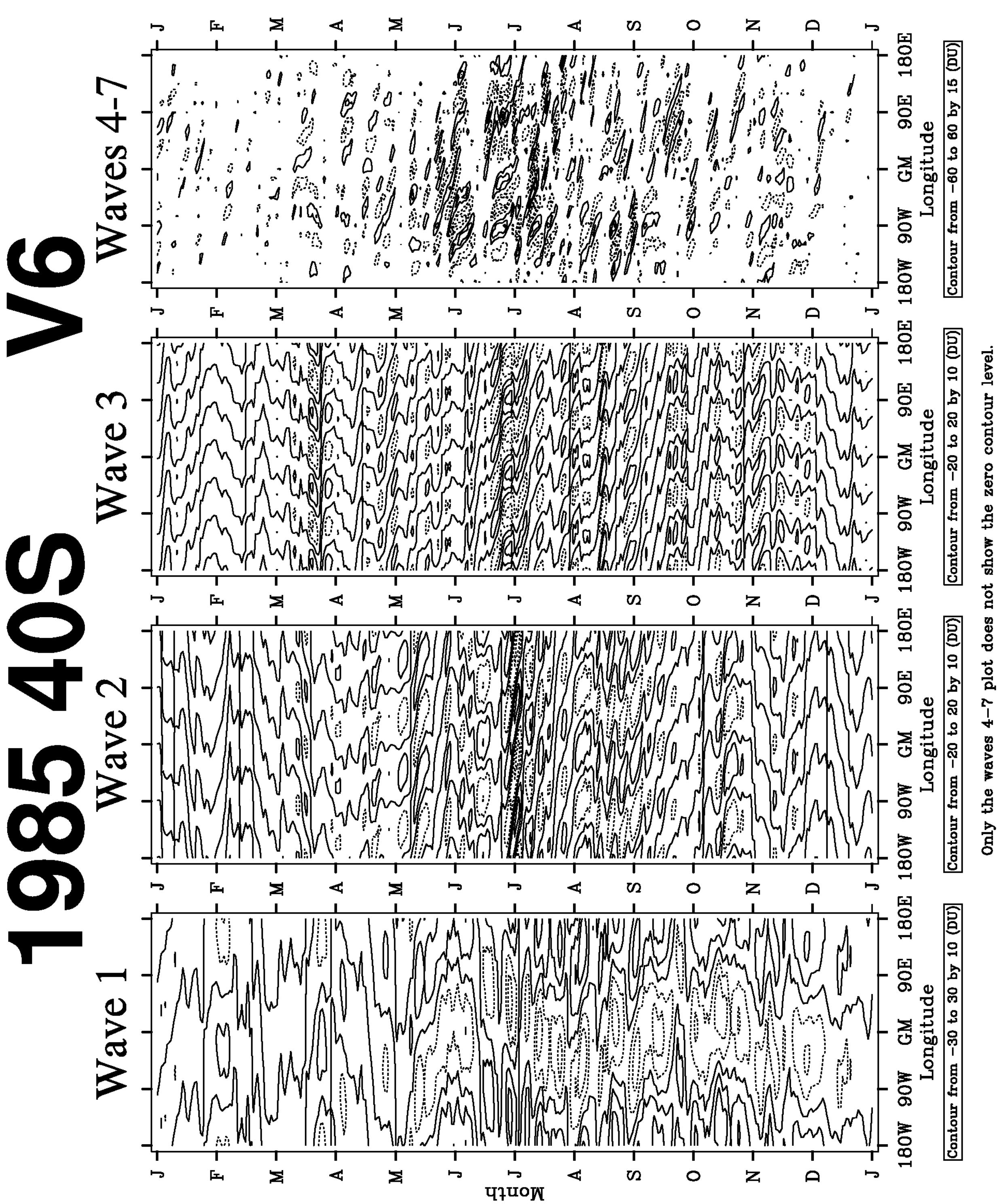

Figure 6. Time versus longitude contour plots of waves 1, 2, 3, and 4-7 in version 6 data at 40° S latitude for 1985. Wave 1 refers to one wavelength around a latitude circle, wave 2 refers to two wavelengths, and so on. Contours slanting downwards from left to right (for example, wave 2 during September) indicate eastward moving wave components.

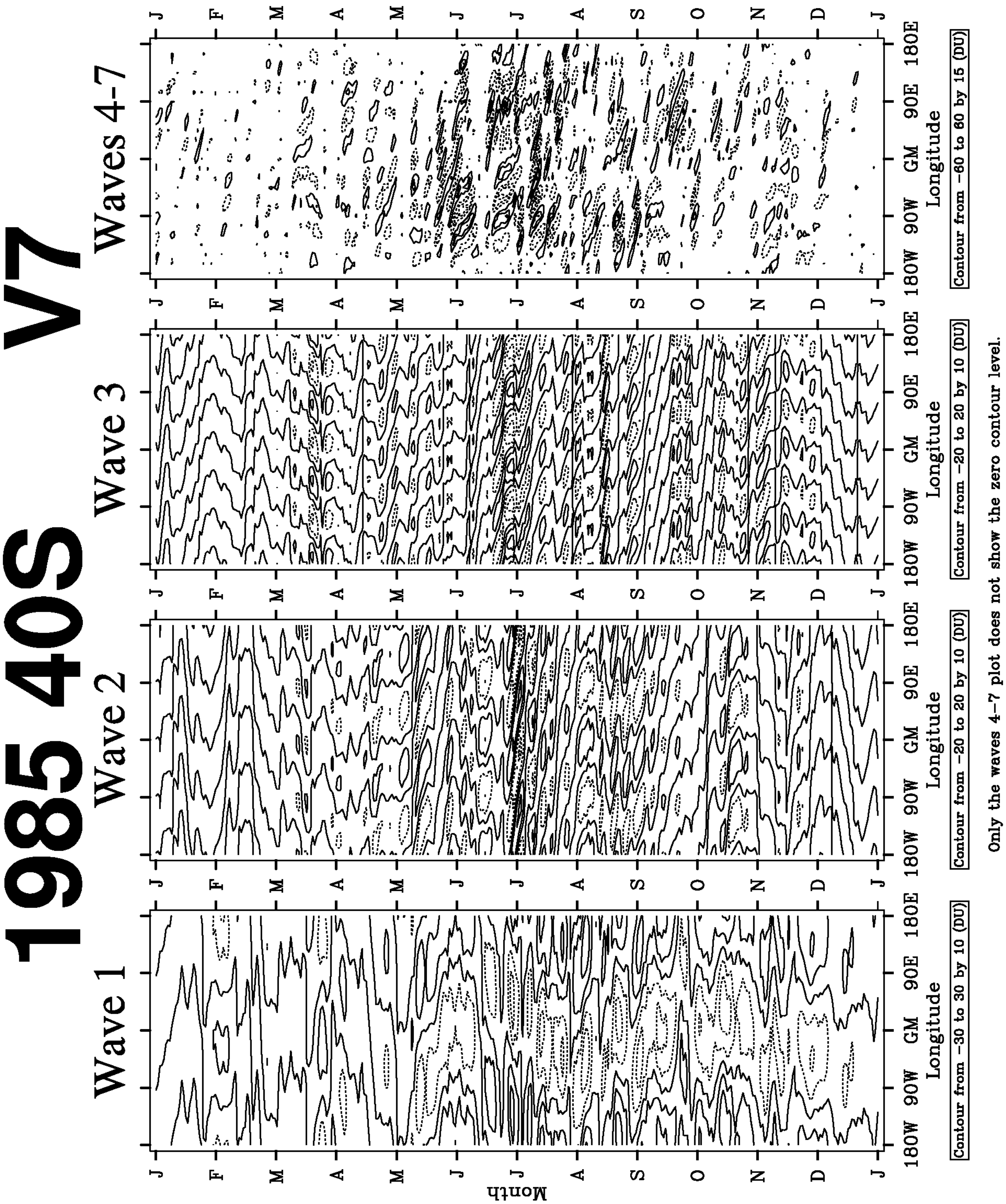

Figure 7. As in Figure 6, but for version 7 data.

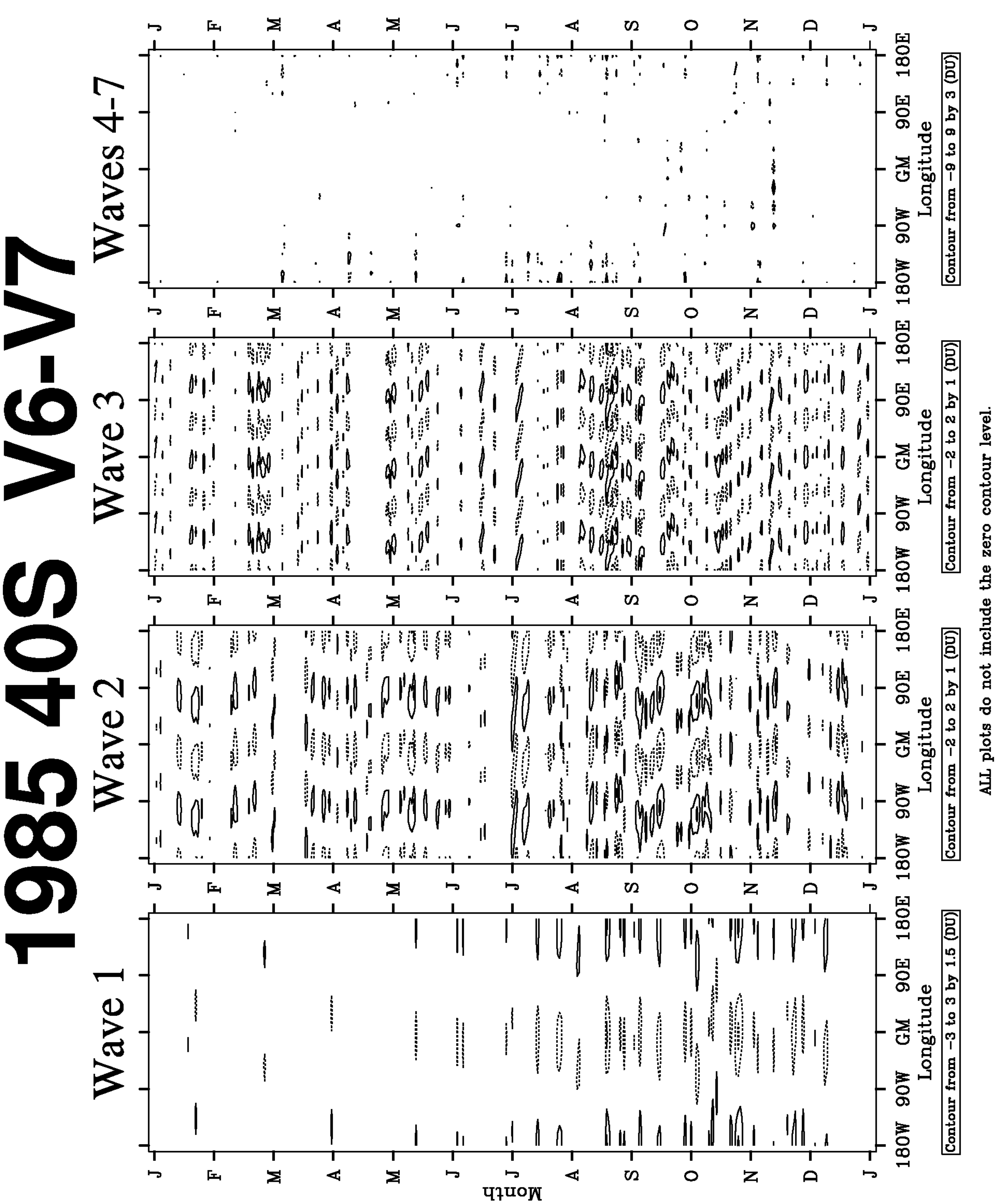

Figure 8. As in Figure 6, but for difference fields of version 7 data subtracted from version 6. Note changes of scale.

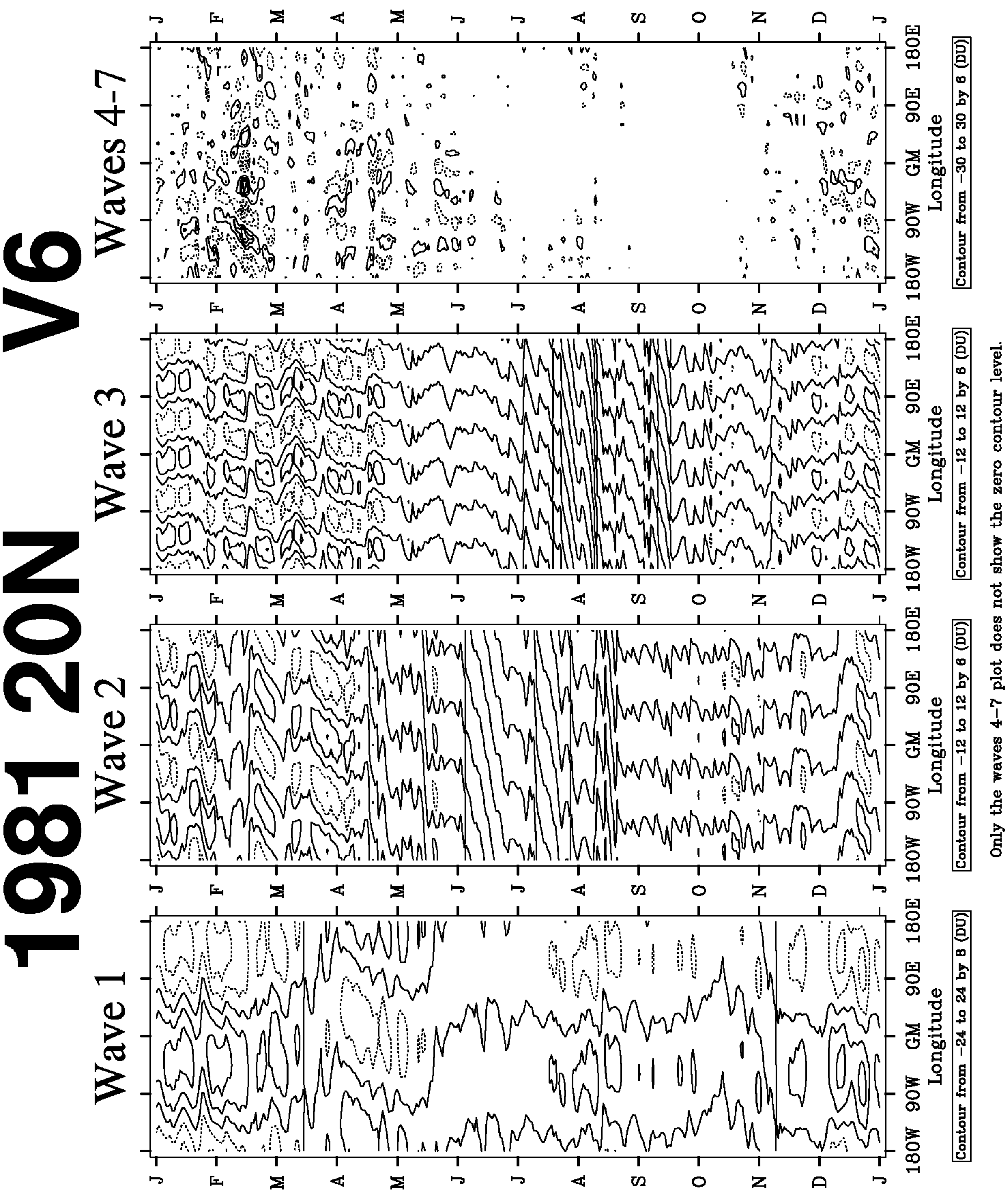

Figure 9. As in Figure 6, but for 1981 at 20° N latitude.

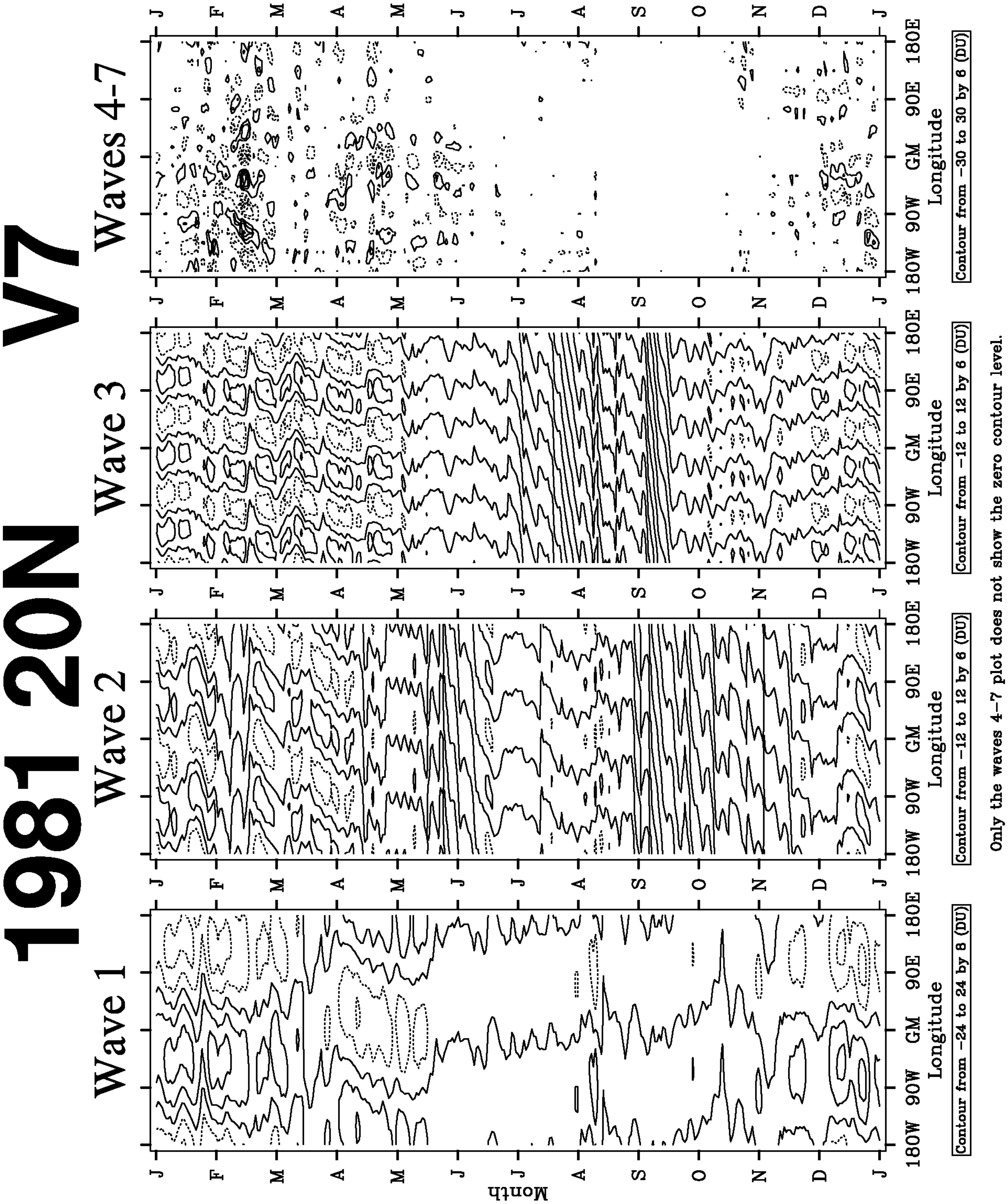

Figure 10. As in Figure 7, but for 1981 at 20° N latitude.

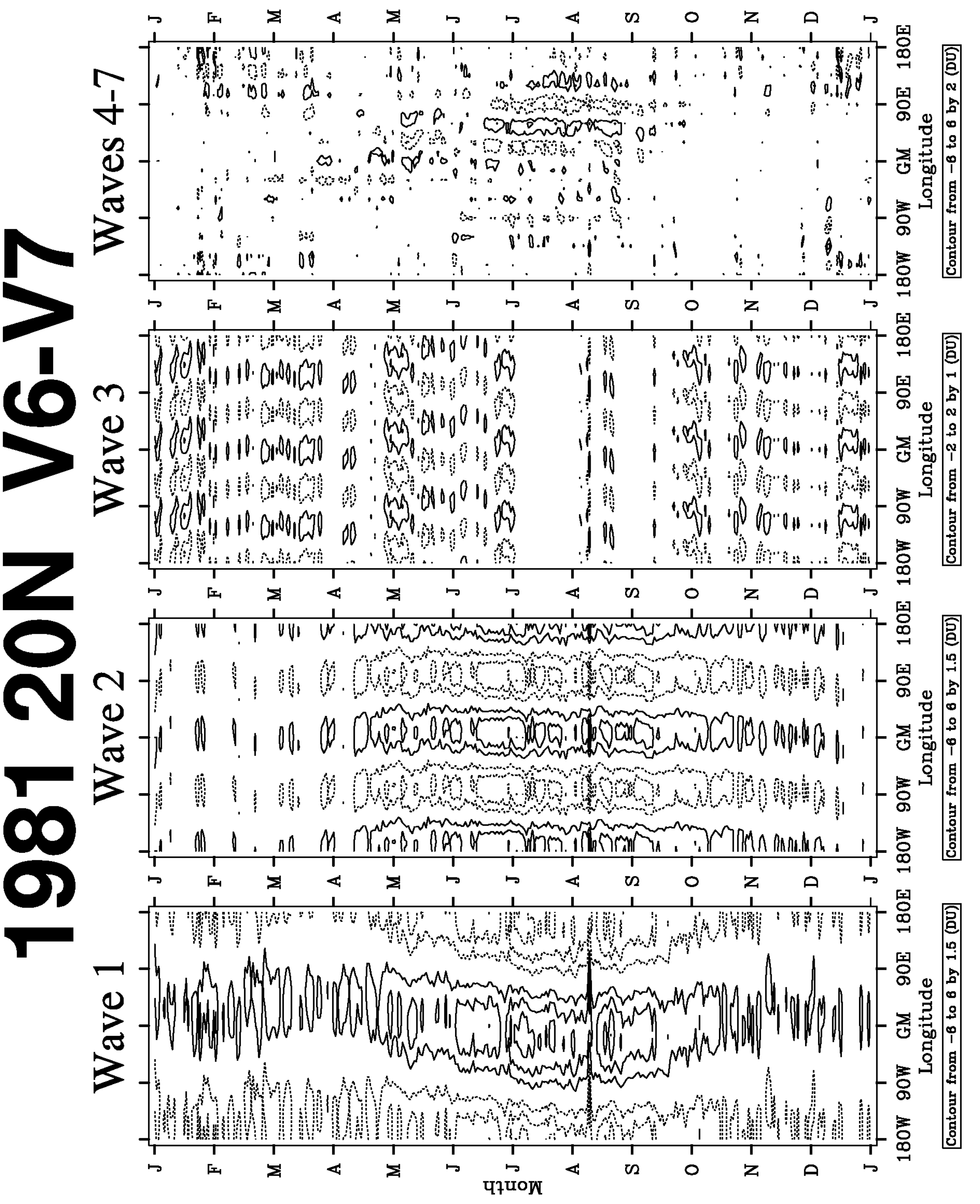

Figure 11. As in Figure 8, but for 1981 at 20° N latitude. Note scale changes.

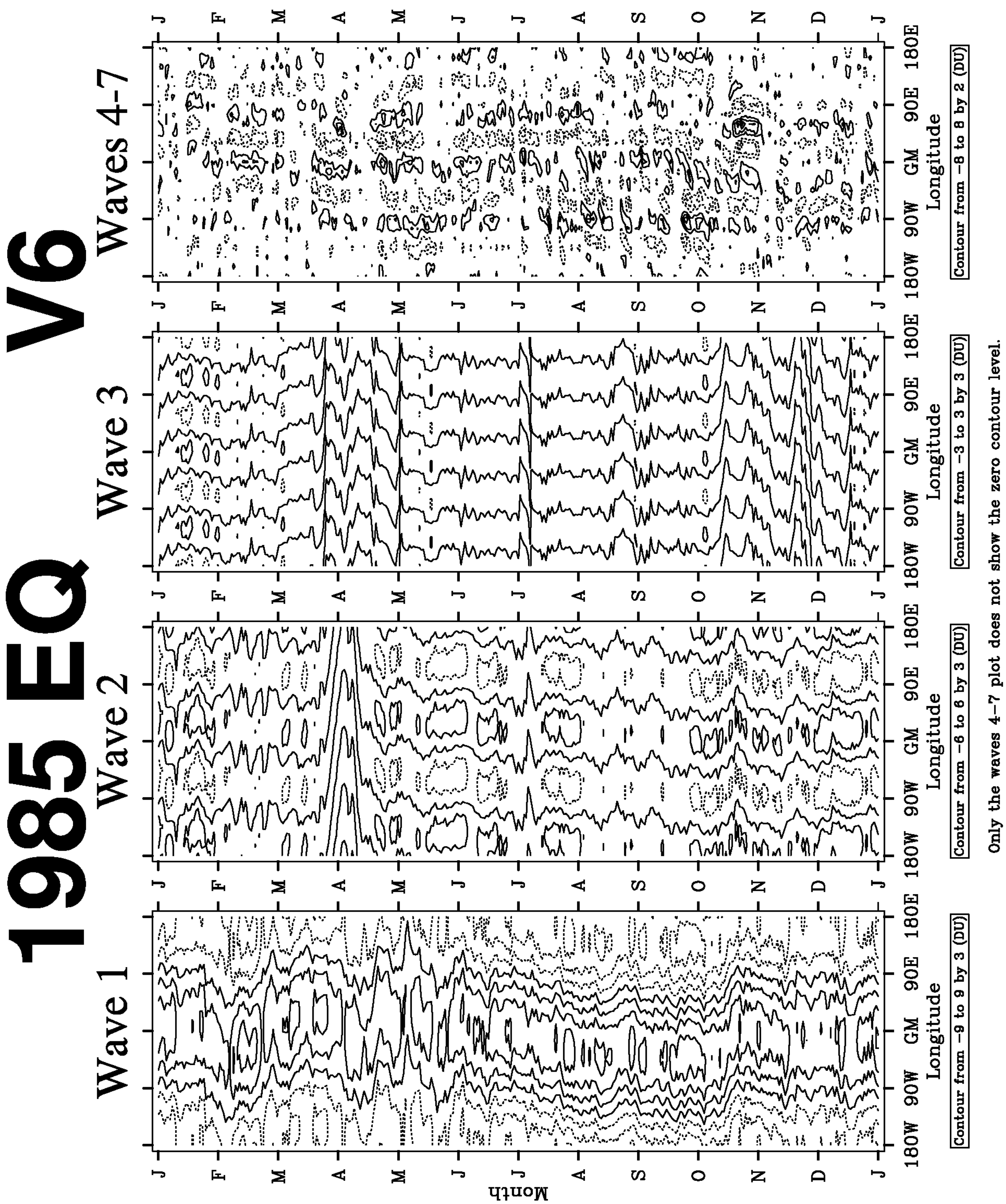

Figure 12. As in Figure 6, but at the equator.

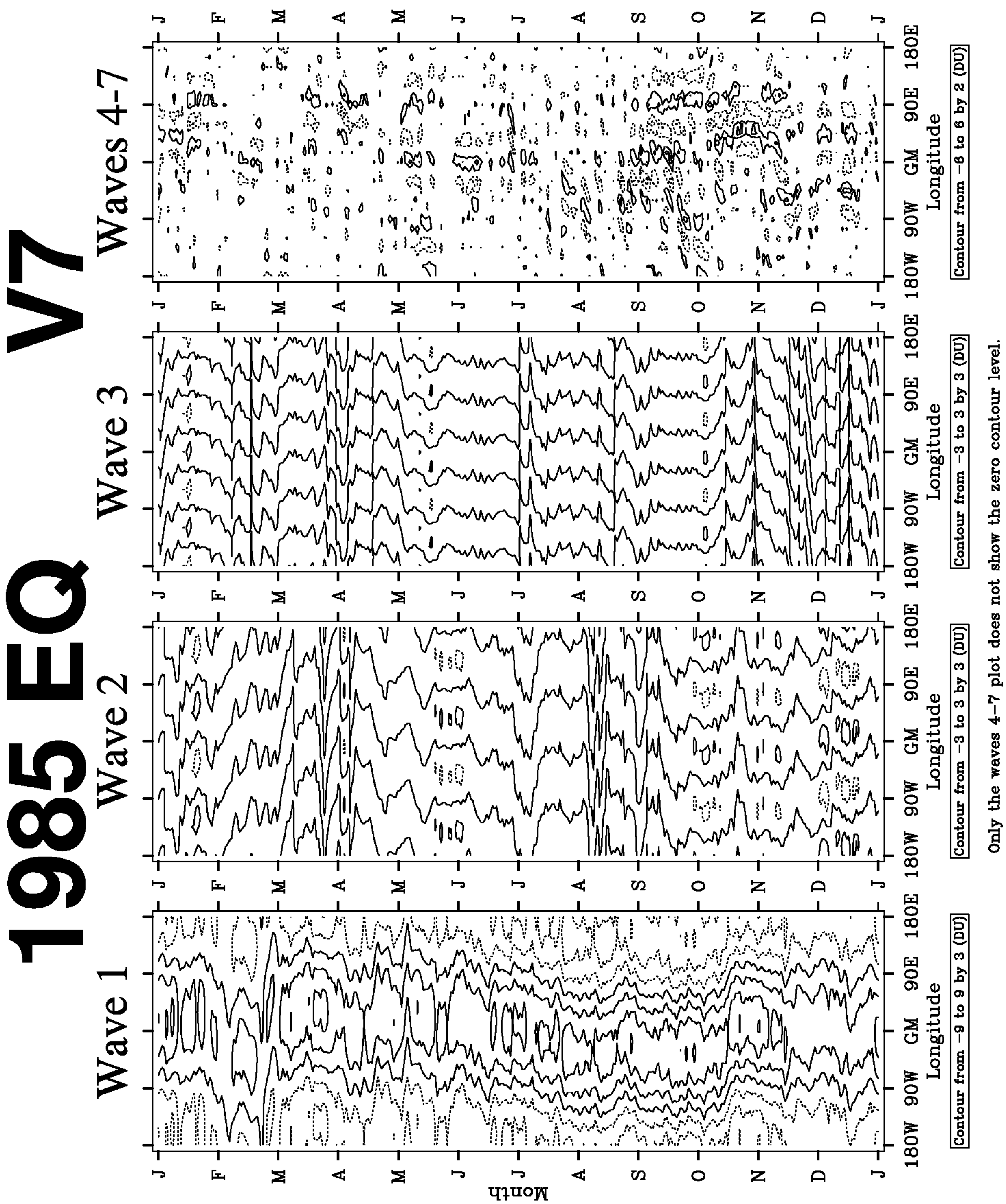

Figure 13. As in Figure 7, but at the equator.

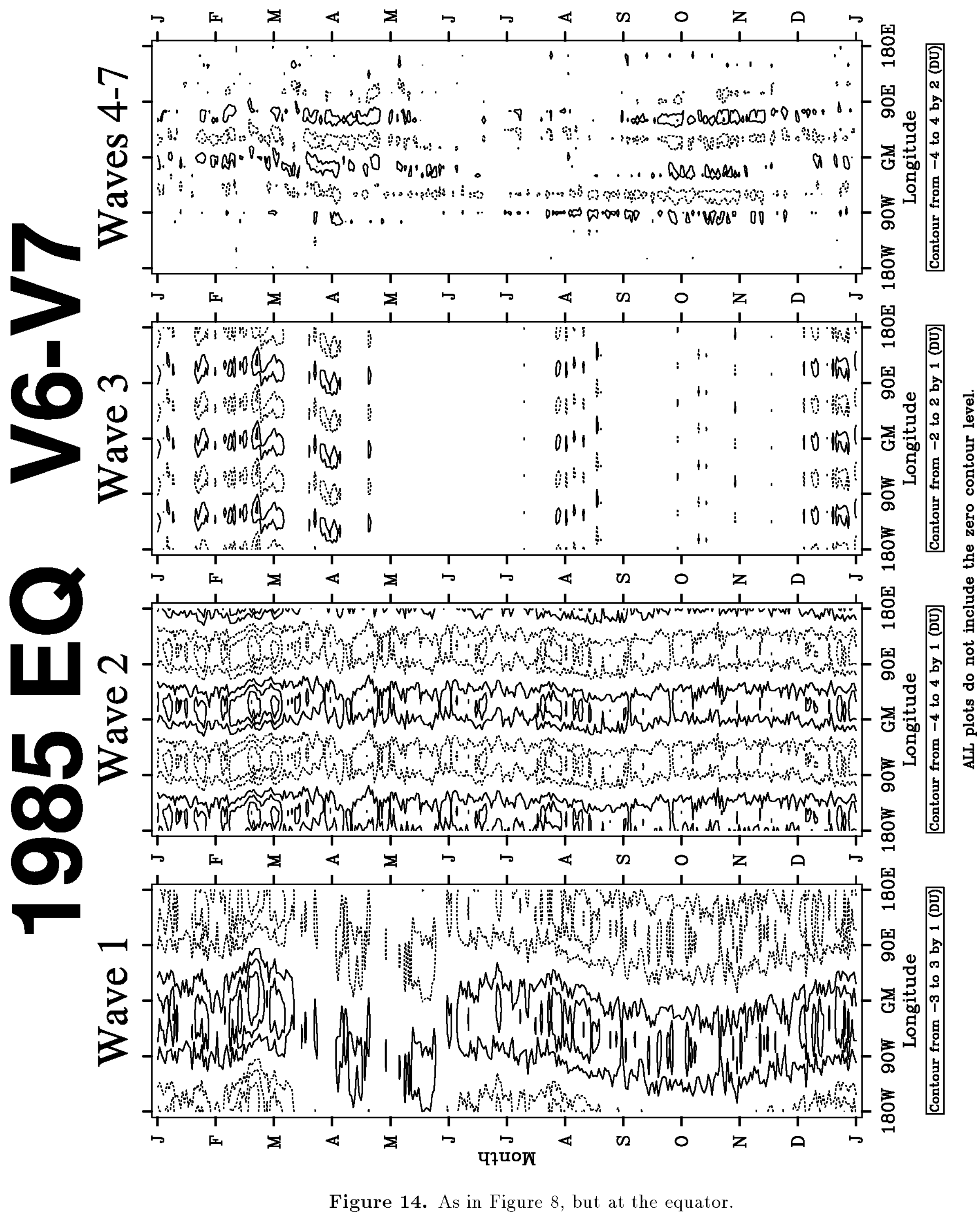

Figure 14. As in Figure 8, but at the equator.

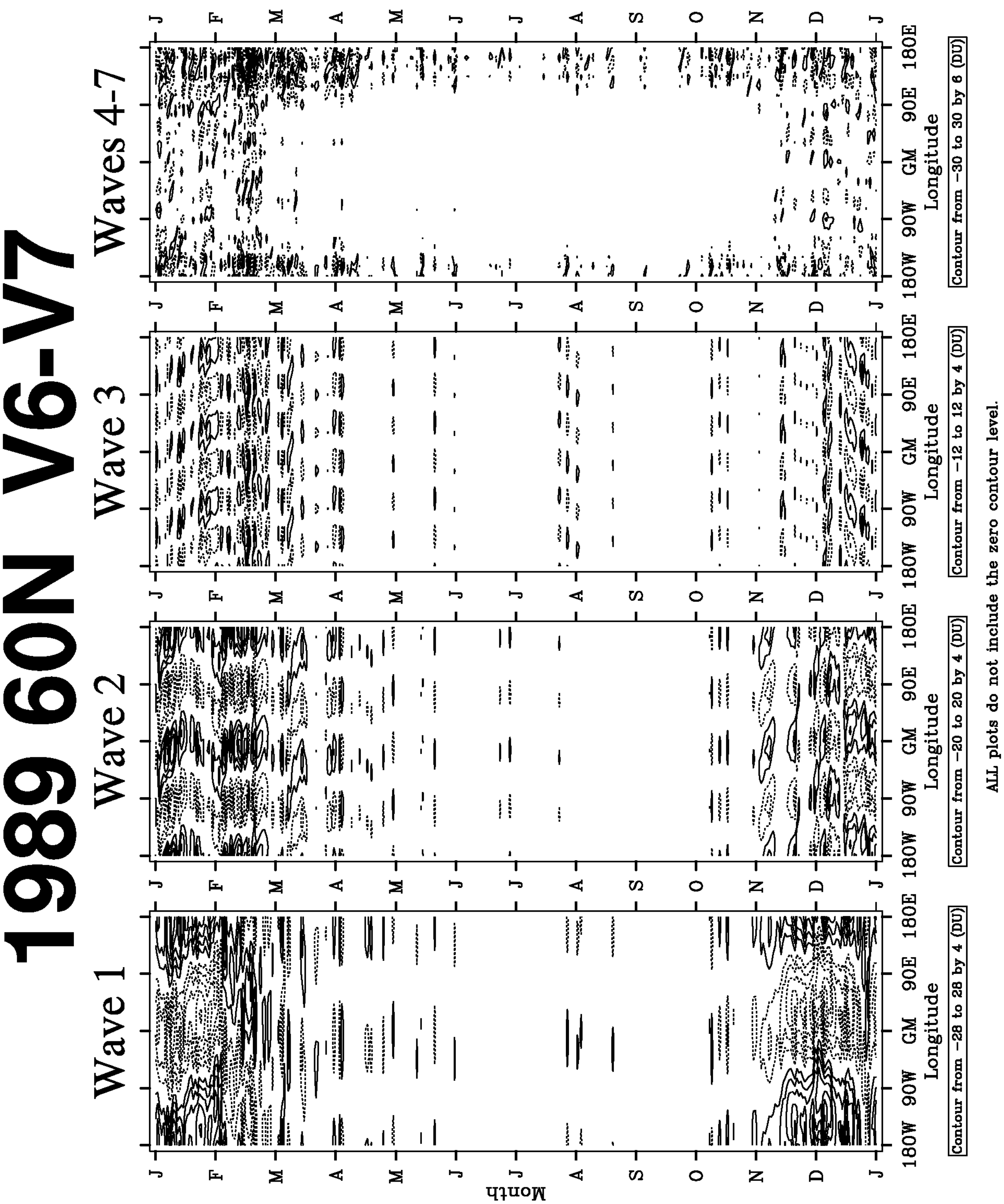

Figure 15. As in Figure 8, but for 1989 at 60° N latitude.

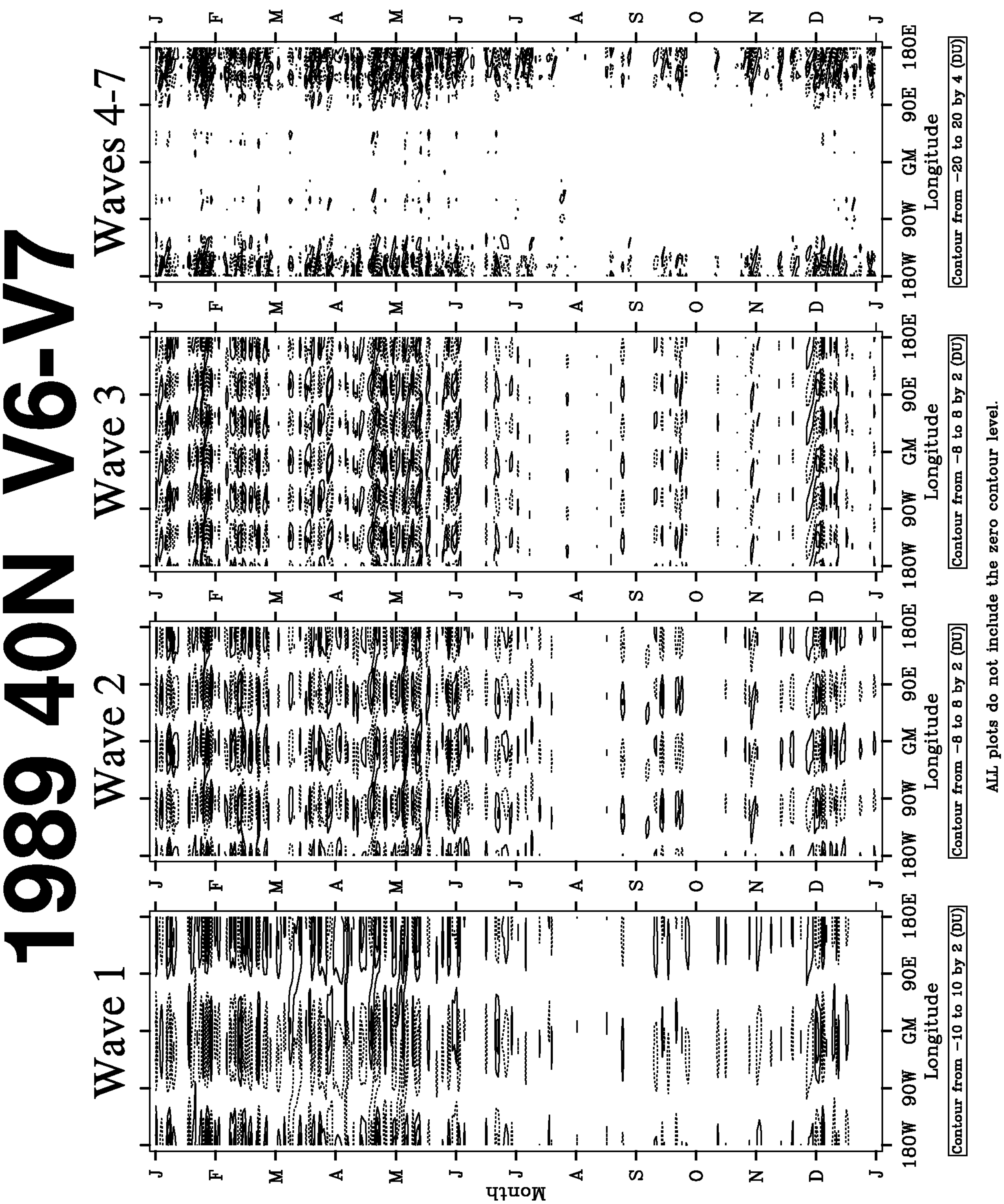

Figure 16. As in Figure 8, but for 1989 at 40° N latitude.

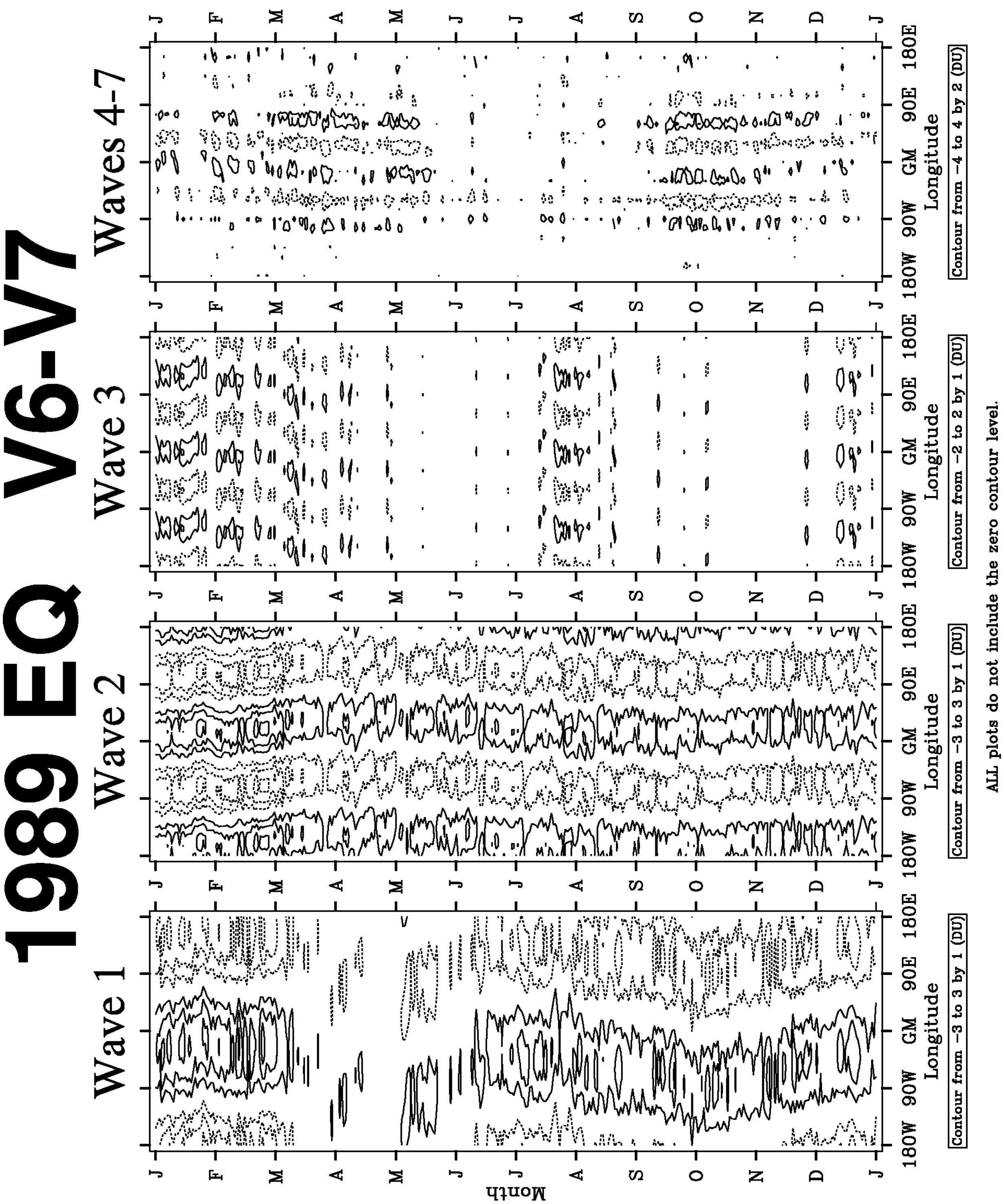

Figure 17. As in Figure 8, but for 1989 at the equator.

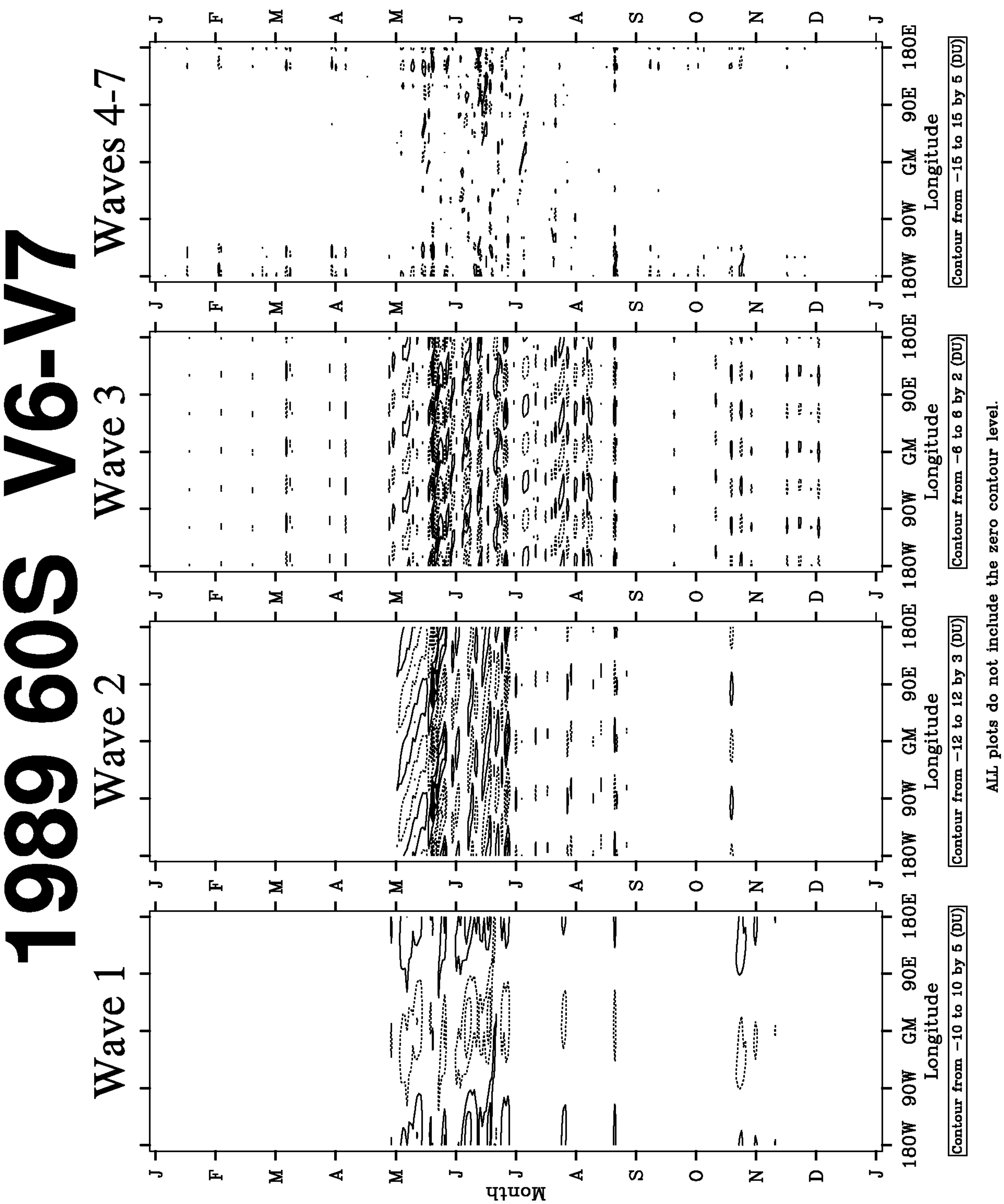

Figure 18. As in Figure 8, but for 1989 at 60° S latitude.

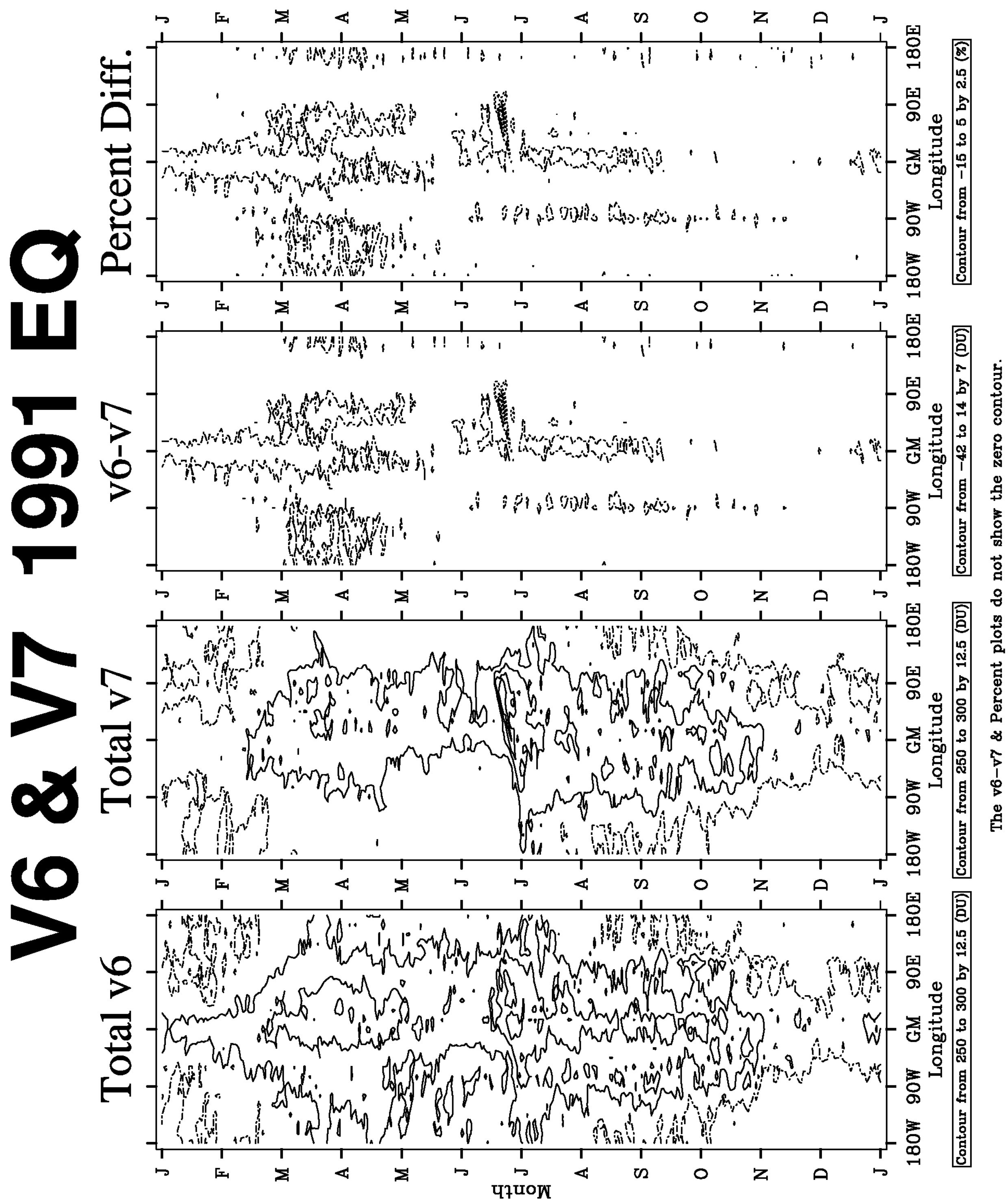

Figure 19. As in Figure 2, but for 1991 at the equator.

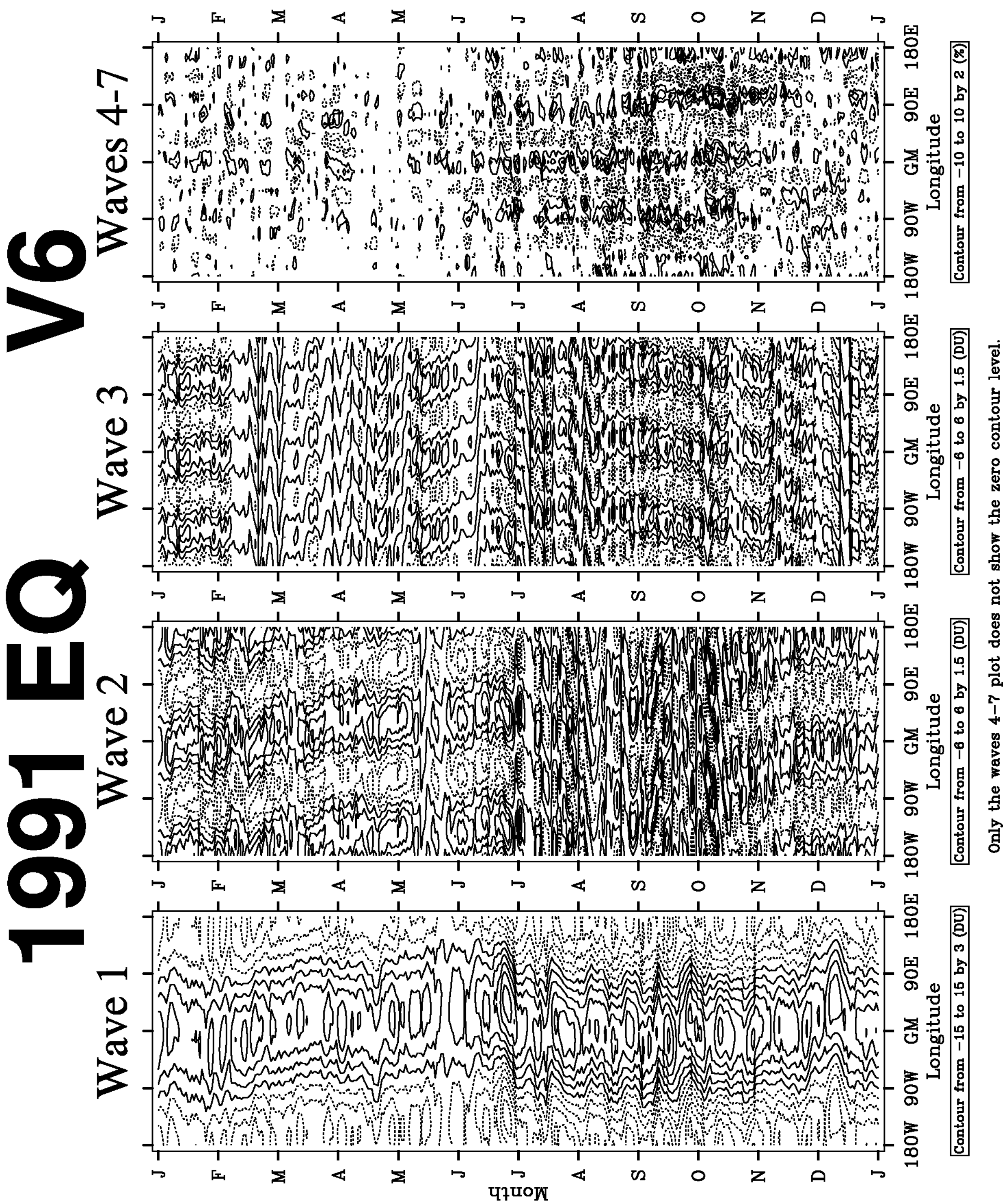

Figure 20. As in Figure 6, but for 1991 at the equator.

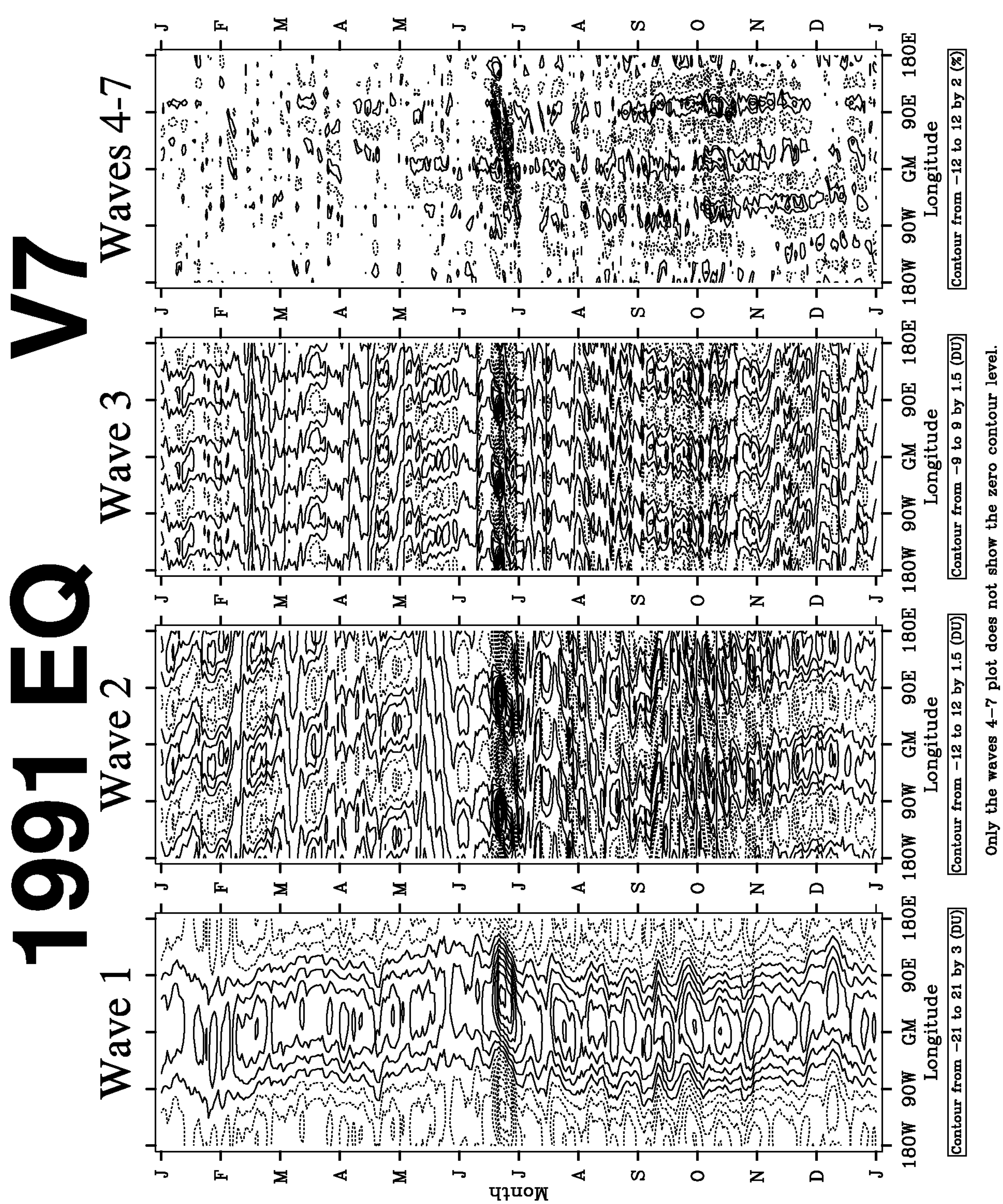

Figure 21. As in Figure 7, but for 1991 at the equator.

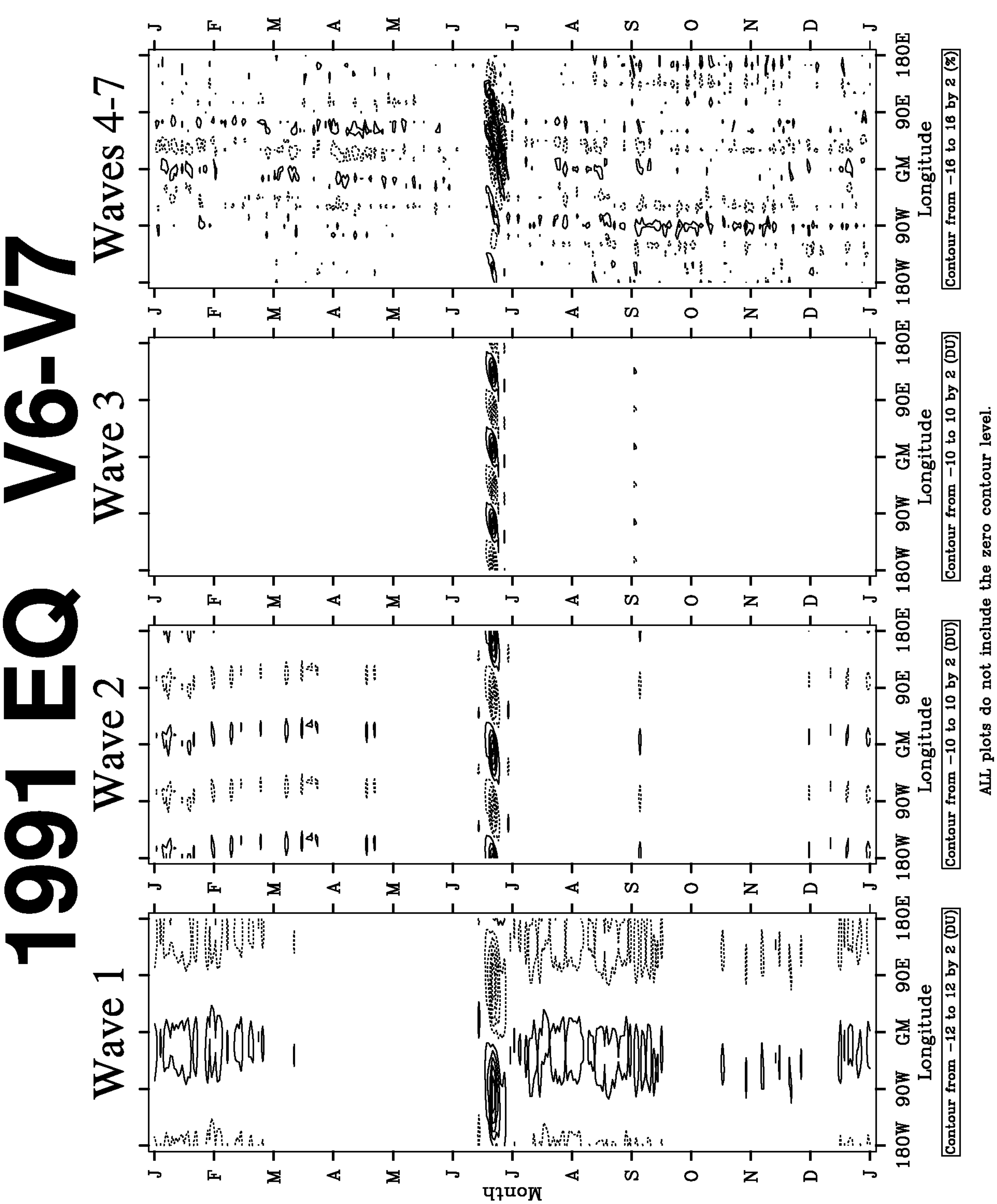

Figure 22. As in Figure 8, but for 1991 at the equator.

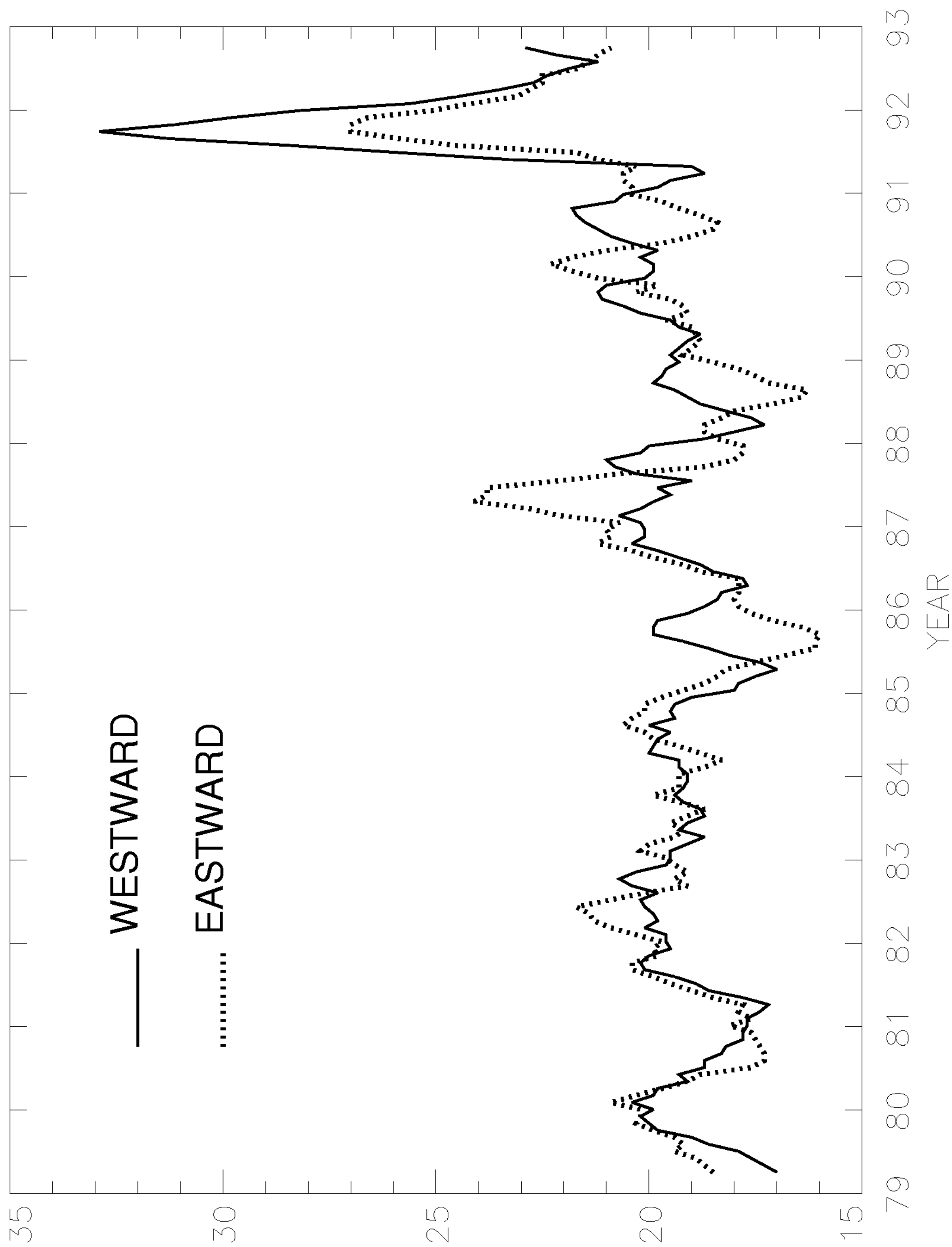

Figure 23. Westward (solid) and eastward (dashed) RMS spectral amplitudes averaged arithmetically over all zonal wavenumbers greater than zero (zonal mean), and plotted versus month. Amplitudes for each wavenumber were computed as in Figure 1, but using a 180-day window with a one-month step. Days: 1 January 1979 - 31 December 1992.

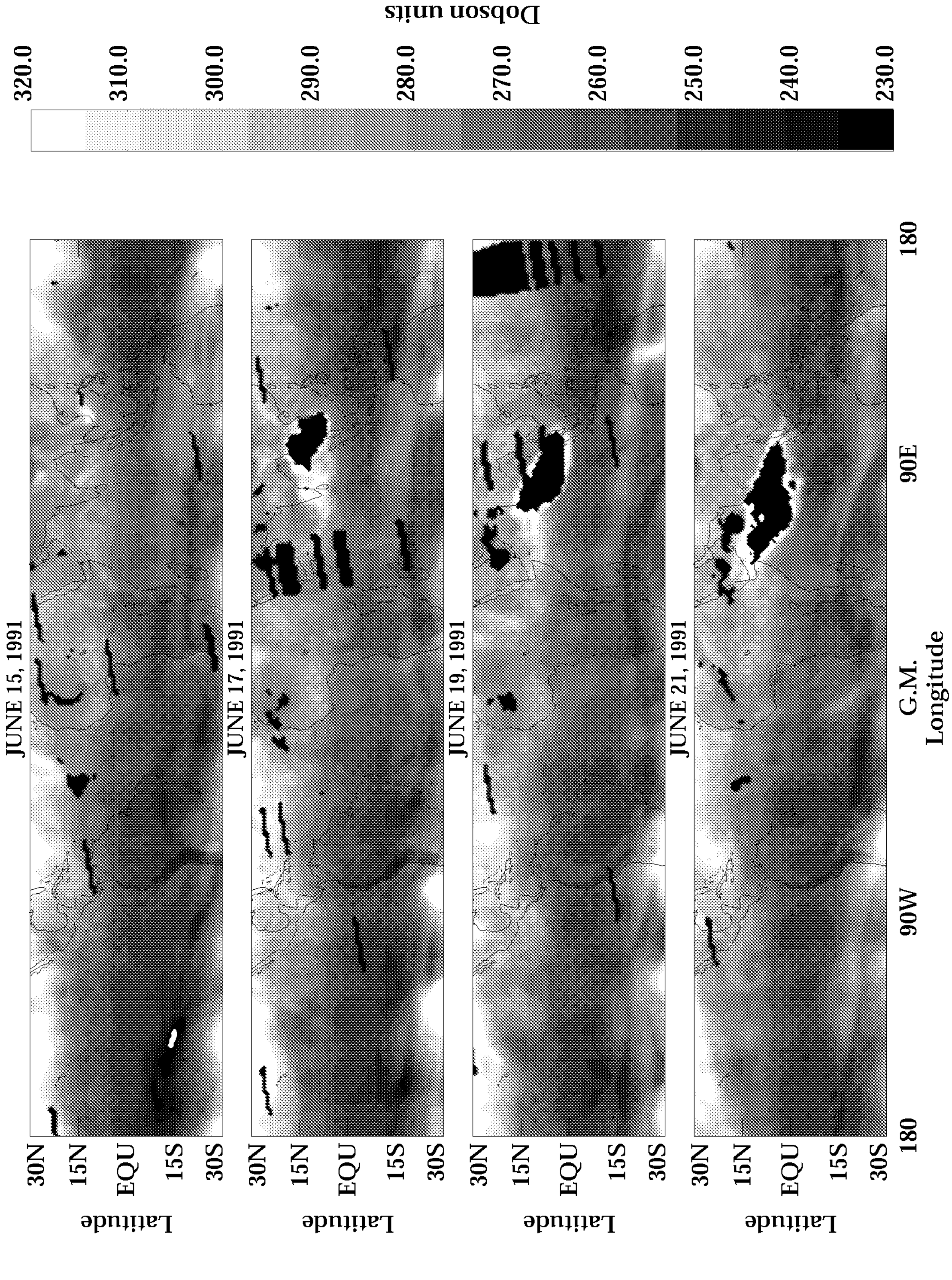

Figure 24. Low-latitude Nimbus-7 version 7 TOMS level 3 (1° latitude by 1.25° longitude gridding) total ozone during days shortly following the eruption of Mt. Pinatubo in mid-June 1991 (indicated).

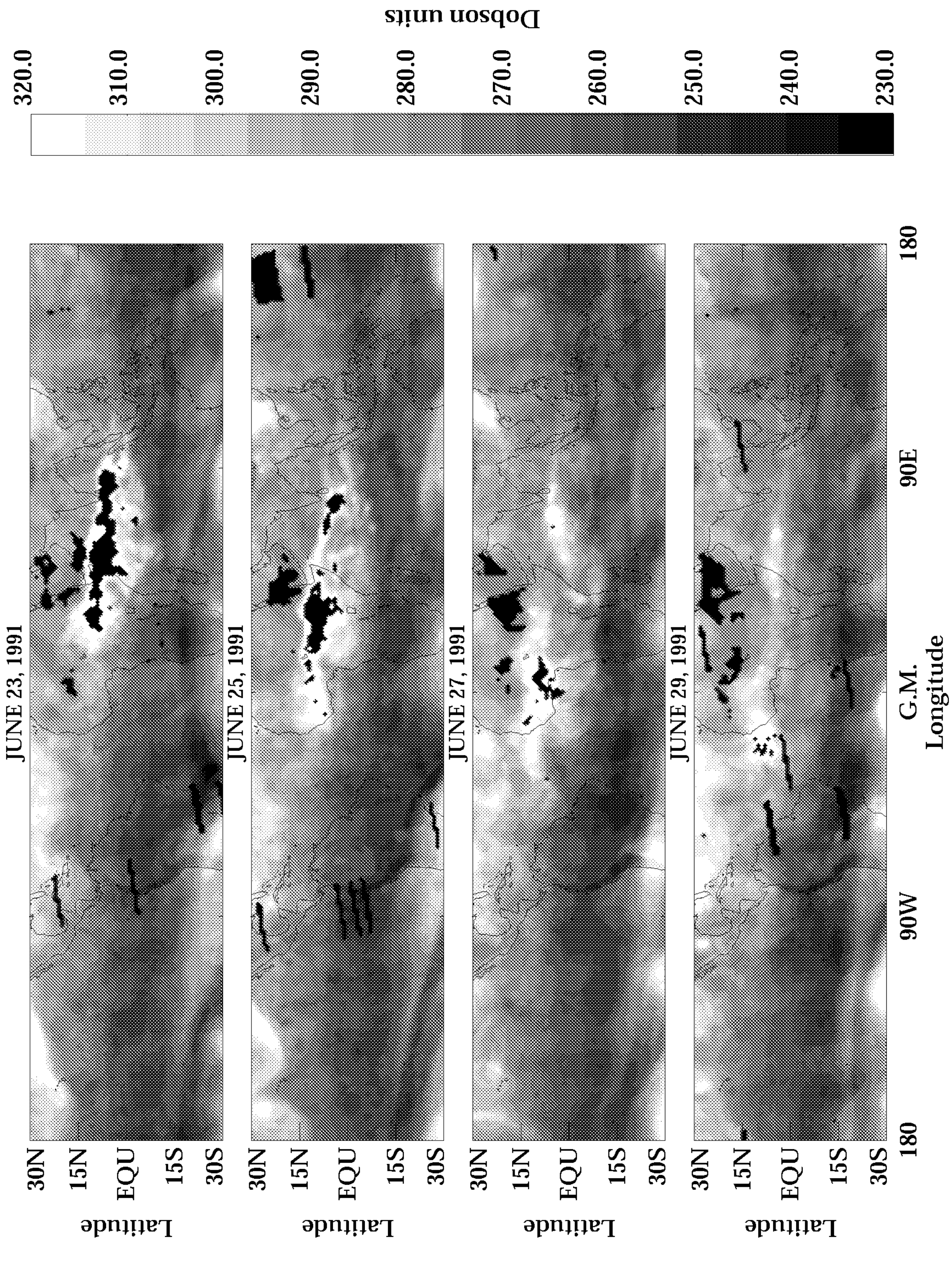

Figure 25. As in Figure 24, but for following days in June 1991.

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13. ABSTRACT *(Maximum 200 words)*
Total column ozone fields from Nimbus–7 Total Ozone Mapping Spectrometer (TOMS) version 7 (V7) data are analyzed by space-time spectral analysis and compared with previous analyses of version 6 (V6) data. One purpose of this note is to briefly comment on some differences between these two data sets. A second purpose is to help prospective TOMS users avoid several pitfalls inherent in analyzing TOMS data. Among the differences noted are improvements in the treatments of the known wave 1 low latitude feature and of large solar zenith angles effects at high latitudes. A variety of low amplitude, traveling features are notes, some of which are atmospheric in origin and some of which may be related to the satellite orbital characteristics or retrieval methods. Interpretations of these in terms of atmospheric dynamics should thus be made with care. Overall, the sensitive tests provided by space-time decomposition suggest that TOMS version 7 constitute an improved global data set valuable for investigations of total ozone.

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